THE INSTITUTION

MECHANICAL ENGINEERS.

PROCEEDINGS.

1901.

PARTS 1-2.

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1901.

PARTS 1-2.

PAST-PRESIDENTS.

GEORGE STEPHENSON, 1847–48. (*Deceased* 1848.)

ROBERT STEPHENSON, F.R.S., 1849–53. (*Deceased* 1859.)

SIR WILLIAM FAIRBAIRN, BART., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

JOHN PENN, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

JAMES KENNEDY, 1860. (*Deceased* 1886.)

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)

ROBERT NAPIER, 1863–65. (*Deceased* 1876.)

JOHN RAMSBOTTOM, 1870–71. (*Deceased* 1897.)

SIR WILLIAM SIEMENS, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

SIR FREDERICK J. BRAMWELL, BART., D.C.L., LL.D., F.R.S., 1874–75.

THOMAS HAWKSLEY, F.R.S., 1876–77. (*Deceased* 1893.)

JOHN ROBINSON, 1878–79.

EDWARD A. COWPER, 1880–81. (*Deceased* 1893.)

PERCY G. B. WESTMACOTT, 1882–83.

SIR LOWTHIAN BELL, BART., LL.D., F.R.S., 1884.

JEREMIAH HEAD, 1885–86. (*Deceased* 1899.)

SIR EDWARD H. CARBUTT, BART., 1887–88.

CHARLES COCHRANE, 1889. (*Deceased* 1898.)

JOSEPH TOMLINSON, 1890–91. (*Deceased* 1894.)

SIR WILLIAM ANDERSON, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

ALEXANDER B. W. KENNEDY, LL.D., F.R.S., 1894–95.

E. WINDSOR RICHARDS, 1896–97.

SAMUEL WAITE JOHNSON, 1898.

SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900.

The Institution of Mechanical Engineers.

OFFICERS.

1901.

PRESIDENT.

WILLIAM H. MAW, ... London.

PAST-PRESIDENTS.

SIR LOWTHIAN BELL, BART., LL.D., F.R.S., ... Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., LL.D., F.R.S., London.
SIR EDWARD H. CARBUTT, BART., ... London.
SAMUEL WAITE JOHNSON, ... Derby.
ALEXANDER B. W. KENNEDY, LL.D., F.R.S., ... London.
E. WINDSOR RICHARDS, ... Caerleon.
JOHN ROBINSON, ... Leek.
PERCY G. B. WESTMACOTT, ... Ascot.
SIR WILLIAM H. WHITE, K.C.B., LL.D., D.SC., F.R.S., .. London.

VICE-PRESIDENTS.

JOHN A. F. ASPINALL, ... Manchester.
BRYAN DONKIN, ... London.
ARTHUR KEEN, ... Birmingham.
EDWARD P. MARTIN, ... Dowlais.
T. HURRY RICHES, ... Cardiff.
J. HARTLEY WICKSTEED, ... Leeds.

MEMBERS OF COUNCIL.

SIR BENJAMIN BAKER, K.C.M.G., LL.D., D.SC., F.R.S., ... London.
SIR J. WOLFE BARRY, K.C.B., LL.D., F.R.S., ... London.
HENRY CHAPMAN, ... London.
HENRY DAVEY, ... London.
WILLIAM DEAN, ... Swindon.
EDWARD B. ELLINGTON, ... London.
H. GRAHAM HARRIS, ... London.
HENRY A. IVATT, ... Doncaster.
SIR W. THOMAS LEWIS, BART. .... Aberdare.
HENRY D. MARSHALL, ... Gainsborough.
THE RIGHT HON. WILLIAM J. PIRRIE, LL.D. .... Belfast.
SAMUEL R. PLATT, ... Oldham.
SIR THOMAS RICHARDSON, ... Hartlepool.
A. TANNETT-WALKER, ... Leeds.
JOHN I. THORNYCROFT, F.R.S., ... London.

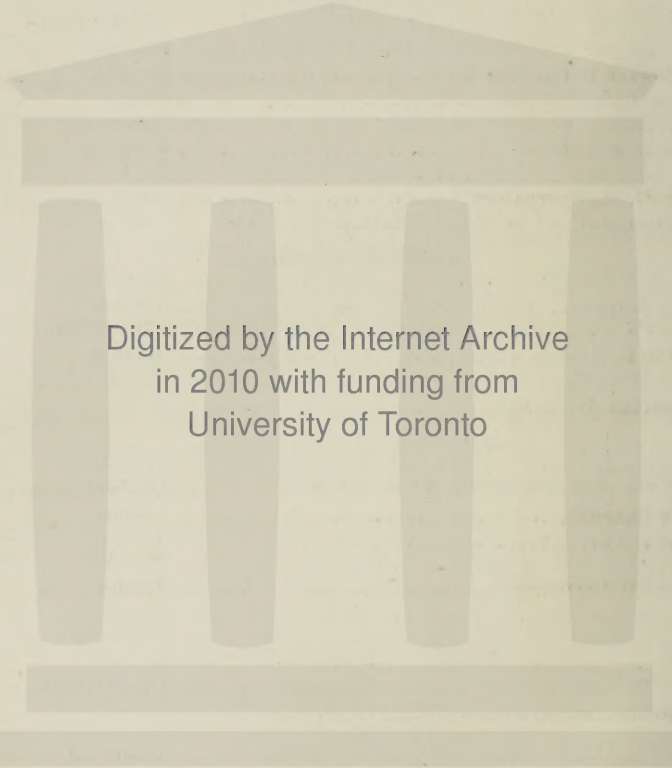| HON. TREASURER.	AUDITOR.
HARRY LEE MILLAR.	ROBERT A. McLEAN, F.C.A.

SECRETARY.

EDGAR WORTHINGTON,

The Institution of Mechanical Engineers, Storey's Gate, St. James's Park,
Westminster, S.W.

Telegraphic address:—*Mech, London.* Telephone:—*Westminster,* 264.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are :—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them : Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited ; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution ; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

FEBRUARY 1893.

INTRODUCTION.

Whereas an Association called " The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply ;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867 ;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ* ;

Now THEREFORE IT IS HEREBY AGREED as follows :—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution ; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum : if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say) :—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(c) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.
(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as .Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution ; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10s., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10s. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10s., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10s. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10s., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10s. additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix.   The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G ; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election ; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

    1st. The Chair to be taken at such hour as the Council may direct from time to time.

    2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

    3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

    4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr.   being   years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this   day of

Members or Associate Members.

FORM B.

Mr.   born on   being desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this   day of

Members or Associate Members.

FORM C.

If elected an   of The Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement (E) and paying the Entrance Fee and Annual Subscription in conformity with the By-laws.

Witness my hand, this   day of

FORM D.

Sir,—I have to inform you that on the   you were elected a   of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are   and   respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary

FORM E.

I, the undersigned, being elected a   of The
Institution of Mechanical Engineers, do hereby agree that I will be governed
by the regulations of the said Institution, as they are now formed or as
they may hereafter be altered; that I will advance the objects of the
Institution as far as shall be in my power, and will attend the Meetings
thereof as often as I conveniently can: provided that, whenever I shall
signify in writing to the Secretary that I am desirous of withdrawing from
the Institution, I shall (after the payment of any arrears which may be due
by me at that period) be free from this obligation.

Witness my hand, this   day of

FORM F.

Mr.   being   years of age, and desirous of being
transferred into the class of   of The Institution of
Mechanical Engineers, we, the undersigned, from our personal knowledge
recommend him as a proper person to be so transferred by the Council.

Witness our hands, this   day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being
transferred to the class of   of The Institution of Mechanical
Engineers. For the ratification of your transference in conformity with the
rules, it is requisite that the enclosed form be returned to me with your
signature, and that your additional Entrance Fee and additional Annual
Subscription for the current year be paid, the amounts of which are
and   respectively. If these be not received within two months
from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of   of The
Institution of Mechanical Engineers, do hereby agree that I will be governed
by the regulations of the said Institution, as they now exist, or as they
may hereafter be altered; that I will advance the objects of the Institution
as far as shall be in my power, and will attend the Meetings thereof as often
as I conveniently can: provided that, whenever I shall signify in writing to
the Secretary that I am desirous of withdrawing from the Institution, I shall
(after the payment of any arrears which may be due by me at that period)
be free from this obligation.

Witness my hand, this   day of

The Institution of Mechanical Engineers.

PROCEEDINGS.

January 1901.

The Fifty-fourth Annual General Meeting was held at the Institution on Friday, 18th January 1901, at Eight o'clock p.m. The chair was taken by the Retiring President, Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., succeeded by William H. Maw, Esq., the President elected at the Meeting.

Before proceeding to business, the President drew attention to the fact that since the last Meeting the Institution had to regret the loss of one of its oldest and most eminent Members, Lord Armstrong. The Council considered that the Members would desire to be represented at the funeral, and arrangements were made accordingly. That day the Council had sent to the surviving relatives an expression of sincerest sympathy with them in their bereavement, and of their sense of the value of the services which Lord Armstrong had rendered to the Institution and to his country. In doing that, the Council felt assured that they were only taking a course which would commend itself to all the Members of the Institution.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following one hundred and twenty candidates were found to be duly elected :—

c

MEMBERS.

AKROYD-STUART, HERBERT,	Fremantle, W.A.
ARAKAWA, SHINICHIRO,	Osaka, Japan.
ASH, ALFRED ELLIS,	London.
BANHAM, CHARLES PROCTER,	Cape Town.
BLAND, FREDERICK,	Sheffield.
BROWETT, THOMAS,	London.
CHAMBERLAIN, JOHN,	London.
CUNLIFFE, RICHARD WILLIAM,	Manchester.
CUNNINGHAM, HUGH,	Banbury.
DELLWIK, CARL,	London.
ELLIS, REGINALD EATON,	London.
ESSON, JOHN,	London.
GIBBS, JOHN HENRY,	Cape Town.
GRAHAM, JESSE,	Bradford.
GREEN, THOMAS,	Rotherham.
HELME, EDWARD TYAS,	Bradford.
HILL, ALFRED JOHN,	London.
HUNT, WILLIAM,	Nottingham.
JENKIN, BERNARD MAXWELL,	London.
LONGSDON, HENRY CROFTS,	Keighley.
MACQUEEN, JOHN,	London.
MERITON, THOMAS HENRY RUDOLPH,	Sunderland.
MOORE, JAMES,	Karachi.
MOORE, WALTER LAUNCELOT, Engr. R.N.,	Cape of Good Hope.
MYERS, HENRY SUTCLIFFE,	Leeds.
STOCKER, PERCY, Engineer R.N.,	East Indies Station.
WHITE, ALFRED FRANCIS,	Tokyo.
WILLIAMS, JOHN NORMAN SPENCER,	Honolulu.

ASSOCIATE MEMBERS.

ATTOCK, FREDERICK WILLIAM,	Horwich.
BALE, JOHN HENRY FOOKS,	Manchester.
BARROW, LOUIS,	Birmingham.
BEAR, MAURICE MAYHEW,	Manchester.
BENNETT, MARSHALL HANDYSIDE,	London.

BOND, JOHN THOMAS, ...	Manchester.
BONNIWELL, PERCIVAL ORMOND, . .	London.
BROWN, JOHN POLLOCK, . . .	Dumbarton.
BROWN, TOM EDWARD BENNETT, . .	London.
CLEAVER, WILLIAM, ...	Port Talbot.
COTTRELL, GEORGE, ...	Hungerford.
CROW, LEWIS, ...	Paisley.
CUMMINS, REGINALD ERNEST, . . .	London.
DARE, ARTHUR NEWMAN, . . .	Budapest.
DEAN, GEORGE, ...	London.
DUNCAN, JOHN, ...	London.
DUNTON, ERNEST WILLIAM, . . .	Whitehaven.
EVETTS, WILLIAM, JUN., . . .	Glasgow.
FORSTER, ANDREW, ...	Cowes.
FOX, EDMUND JOHN, ...	Chelmsford.
GAWTHORNE, WILLIAM ARTHUR, . .	Bombay.
GIBBONS, JAMES OLLIFF GRIFFITS, . .	Manchester.
GORE, HERBERT REGINALD, . . .	London.
GUTHRIE, ALLAN, ...	Glasgow.
HARRIS, HENRY EVANS, . . .	Madras.
HARRIS, WILLIAM ROBERT ALEXANDER, .	Wooburn, Bucks.
HISLOP, GEORGE ROBERTSON, JUN., .	Paisley.
HODSDON, GEORGE CHARLES, . . .	London.
HOLLICK, AUBREY SAMUEL, . . .	London.
JONES, WILLIAM EDWIN, . . .	London.
KNIGHT, ARTHUR HENRY, . . .	Veile, Denmark.
KNOTTESFORD-FORTESCUE, JOHN NICHOLAS,	Cardiff.
LESTER, JOHN MILNER, . . .	London.
LIVESEY, ROBERT MARTYN, . . .	Gibraltar.
LYDDON, GEORGE EDWARD, . . .	Ilford.
MAIN, GEORGE PEET, ...	Leamington.
MARTYN, SARSFIELD WILLIAM, . .	Mullingar.
McKERLIE, JAMES, ...	Salford.
MORRIS, ROBERT EDMUND, . . .	London.
PARSONAGE, WILLIAM RAWLETT, . .	Birmingham.
PEET, WILLIAM WENTWORTH, . .	Carrigaline, Cork.

PERKINS, WILLIAM JOHN,	Devizes.
RASEY, ALFRED ERNEST,	London.
REYNOLDS, ALFRED MILWARD,	Birmingham.
RIVIERE, PHILIP LYLE,	London.
ROBINSON, SYDNEY GREENWOOD,	London.
ROCK, JAMES PARTHENAY,	London.
ROSE, SYDNEY DURRANT,	Hungerford.
RUSSELL, WILLIAM RUSSELL,	Plymouth.
SCOTT, THOMAS,	London.
SHEFFIELD, THOMAS WILLIAM,	Manchester.
SMITH, LIONEL LINCOLN,	Woolwich.
STRATHERN, ALEXANDER GEORGE,	Gartsherrie, N.B.
STUBBS, HERBERT,	Wolverhampton.
SUMMERFIELD, RICHARD DUNNING,	London.
SWAINE, ALBERT TOM,	London.
TAYLOR, TOM,	Manchester.
THOMAS, WALTER FREDERICK,	Birmingham.
THOMSON, DAVID LOCKERBIE,	Nickerie, Dutch Guiana.
THOMSON, JAMES CUNNINGHAM,	Tientsin.
URMSTON, PETER,	Moscow.
WEAVER, HENRY JAMES,	King's Lynn.
WOODGER, PETER BISSET,	Plymouth.
WRIGHT, FRANK,	London.
YARDLEY, WILLIAM HENRY,	Sheffield.

ASSOCIATE.

MAYHEW, MARK JAMES,	London.

GRADUATES.

DAVIDSON, JAMES SAMUEL,	Belfast.
DENNIS, GEORGE STANLEY,	London.
DROWN, ALFRED ERNEST,	London.
ELLIOTT, ALEXANDER GRAY,	Belfast.
ELLIS, RHODES HERBERT,	Bradford.
FORSTER, RICHARD,	Sheffield.
HAMILTON, JOHN, R.N.,	London.

HEAD, WALTER GEORGE,	London.
HERBERT, WALTER,	Leicester.
HURST, JOSEPH HENRY,	Leicester.
JENKINS, EDGAR JACKSON,	Chesterfield.
MAYO, CHARLES ROBERT,	Crewe.
McDONALD, WILLIAM,	Dundee.
NEWMAN, KENNETH CHARLES HORTON,	London.
PENN, REGINALD WILLIAM,	London.
REEVES, CHARLES INGHAM,	London.
RESIDE, ANDREW,	Brighouse.
SHARPLEY, REGINALD,	London.
SMITH, REGINALD REDHEAD,	London.
SPENCER, ARTHUR JOHN,	London.
TAYLOR, GEORGE STEVENSON,	London.
THOMPSON, EDGAR WAKELIN,	Bombay.
WARNER, HAROLD MELFORD,	London.
WILKINSON, FRANK,	Rochdale.
WINDSOR, ARTHUR WHALESBY,	London.
WINGATE-SAUL, ARTHUR WINGATE,	London.

TRANSFERENCES.

The PRESIDENT announced that the following five Transferences had been made by the Council:—

Associate Members to Members.

CLARK, GEORGE,	Chesterfield.
PARISH, CHARLES EDWARD,	Chester-le-Street.
RUSSELL, BRIDGMAN,	London.
WILLIAMS, HENRY WATSON,	Fremantle, W.A.

Associate to Associate Member.

PHILLIPPS, JOHN,	Nottingham.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.
1901.

The Council have pleasure in presenting to the Members the following Report of the progress and work of the Institution during the past year.

Her Majesty the Queen has conferred the honour of a Baronetcy upon Mr. Thomas Wrightson, M.P.

At the end of 1900, the number in all classes on the roll of the Institution was 3,165, as compared with 2,922 at the end of the previous year, showing a net gain of 243. During the year there were added to the register 343 names; and the total deductions were 100, made up of 39 deceases during 1899 (see Report of 1899), 43 resignations which took effect on 1st January 1900, and 18 removals.

The following thirty-five Deceases of Members of the Institution were reported as having occurred during the year 1900 :—

AMOS, JAMES CHAPMAN, ...	Teddington.
ARMSTRONG, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S. (Past-President), ...	Morpeth.
ARMSTRONG, Professor GEORGE FREDERICK, F.R.S.E., .	Edinburgh.
ATKINSON, EDWARD, ...	London.
BARKER, FREDERIC WILLIAM (Associate Member), .	London.
BINGHAM, CHARLES HENRY, ...	Sheffield.
BIRCH, JOHN GRANT (Associate), ...	London.
BORROWS, WILLIAM, ...	St. Helens, Lancs.
BRUCE, WILLIAM DUFF, ...	London.
BUCKNEY, THOMAS, ...	London.
CARBACK, JOHN WILLIAM (Associate Member), . .	Nottingham.

DANIELS, THOMAS,	Manchester.
DAWSON, BERNARD,	Malvern.
EDDISON, ROBERT WILLIAM,	Leeds.
FLETCHER, GERARD MURRAY (Graduate),	Ruabon.
FULCHER, GEORGE CHAMBERS (Associate Member),	London.
GARBUTT, HENRY (Associate Member),	Birmingham.
GÖRANSSON, GÖRAN FREDRICK,	Sandvik, Sweden.
JEFFERIES, JOHN ROBERT,	Ipswich.
JOHNSON, JOHN CLARKE,	Wednesbury.
KENNEDY, ROBERT BAIRD (Associate Member),	Middlesbrough.
MACNAB, JAMES (Associate Member),	Hyde, Manchester.
MARSHALL, Rev. ALFRED,	Redditch.
McQUEEN, JOHN,	Manchester.
MILES, FREDERICK HUDSON (Graduate),	Lahore, India.
MOIR, JAMES,	Bombay.
RATLIFFE, GEORGE,	London.
SEYMOUR, LOUIS IRVING,	Johannesburg.
STRACHAN, JAMES,	London.
THOMAS, JAMES DONNITHORNE,	London.
THOMAS, THOMAS,	Cardiff.
WATERHOUSE, THOMAS,	Sheffield.
WATSON, Sir WILLIAM RENNY,	Glasgow.
WILDRIDGE, JOHN,	Sydney.
WYLLIE, ANDREW,	Southport.

Lord Armstrong had been a Member since 1858, and the prominent part he took in the earlier years of the Institution is shown by his having been a Vice-President in 1859 and 1860, and President in 1861, 1862, and 1869.

The Accounts for the year ended 31 December 1900 are now submitted to the Members (see pages 12–15 and 16), having been duly certified by Mr. Robert A. McLean, F.C.A., the Auditor appointed by the Members at the last Annual General Meeting.

The total revenue for the year 1900 was £9,005 8s. 1d., while the expenditure was £8,595 11s. 1d., leaving a balance of revenue over expenditure of £409 17s. 0d. The financial position of the Institution at the end of the year is shown by the balance sheet. The total investments and other assets amount to £70,117 1s. 5d.; and, deducting therefrom the £25,000 of debentures and the total remaining liabilities £4,211 15s. 6d., the capital of the Institution

amounts to £40,905 5s. 11d. Of this sum £5,000 was set aside
in 1897 and 1898 for the redemption of the debentures. The sum
of £6,859 4s. 8d. still remains invested in Railway Debenture
Stocks and Consols, registered in the name of the Institution, of
which the Union Bank of London holds the £3,945 12s. Midland
Railway 2½ per cent. Debenture Stock and £1,000 Consols (2¾ per
cent.) as security for a temporary loan of £3,250. A total of
£60,270 2s. 10d. has now been expended upon the Institution House.
The certificates of the securities have been duly audited by the
Finance Committee and the Auditor.

During the year the expenditure on the New House was
£1,056 2s. 3d., and the total indebtedness to the Union Bank of
London at the end of the year amounted to £3,836 19s. 2d., as shown
in the Accounts.

The award of the Willans Premium has been for the first time
in the gift of the Council, and, from the Papers read before the
Institution since the foundation of the Fund in January 1895, they
have selected that read in April 1895 by Captain H. Riall Sankey,
on " Governing of Steam-Engines by Throttling and by Variable
Expansion," as the most suitable for the award.

Sir William C. Roberts-Austen is still at work upon the Sixth
Report to the Alloys Research Committee, dealing mainly with the
Effect of Annealing and Tempering on the Properties of Steel. This
Report will be ready during the coming year.

Professor F. W. Burstall expects to complete his Second Report to
the Gas-Engine Research Committee in the course of a few weeks.

Progress has been made in the experiments on the Value of the
Steam-Jacket by Professor T. Hudson Beare.

Professor David S. Capper has made a first series of tests on the
Compound Steam-Jacketed Engine at King's College with different
steam-pressures and speeds, working single-cylinder, non-condensing.
The results have been worked out, and are expected to be ready
shortly.

With a view to the formation of a historical museum, relating to Mechanical Engineering progress, several gifts of value have been promised. Members are invited to help with suitable contributions of drawings and models.

The Library has received a number of new works and publications of various societies and public authorities, also technical periodicals from members and others, as enumerated in pages 18 to 28. For these the Council here record their thanks to the several donors.

In addition to the Ordinary Monthly Meetings, the Summer Meeting, extending over three days in June, was held in London, when the Members of the American Society of Mechanical Engineers accepted the invitation of the Institution, and attended the business meetings and the excursions in considerable numbers. The numerous letters which have since been received from the United States evince a thorough appreciation of the reception accorded to the visitors by the Institution.

The pleasure of this meeting was much enhanced by the kindness and hospitality of Messrs. Willans and Robinson, Mr. Walter Hunter, Mr. R. E. Middleton, Messrs. Aird and Sons, and other members and friends who opened their works in London and the neighbourhood to the visit of the members and visitors.

The nine Meetings of the Institution were occupied by the reading and discussion of the following Papers :—

Water Meters of the present day ; with special reference to small flows and waste in dribbles ; by Mr. William Schönheyder.

Improvements in the Longworth Power-Hammer ; by Mr. Ernest Samuelson.

Portable Pneumatic Tools ; by Mr. Ewart C. Amos.

Road Locomotion ; by Professor H. S. Hele-Shaw, LL.D., F.R.S.

The Recent 1,000 Miles Road Trials ; by Professor H. S. Hele-Shaw, LL.D., F.R.S.

Notes on the Construction of " Long Cecil," a 4·1-inch rifled breech-loading Gun, in Kimberley, during the Siege, 1899–1900 ; by Mr. Edward Goffe.

Recent Locomotive Practice in France ; by Professor Edouard Sauvage, Ingénieur des Mines.

Polyphase Electric Traction ; by Professor C. A. Carus-Wilson.

Observations on an improved Glass Revealer, for studying Condensation in Steam-Engine Cylinders, and rendering the effects visible ; by Mr. Bryan Donkin, Member of Council.

Capacity of Railway Wagons as affecting Cost of Transport; by Mr. J. D.
    Twinberrow.
Power-Gas and Large Gas-Engines for Central Stations; by Mr. Herbert A.
    Humphrey.

It is a pleasure to record that the introduction of Monthly
instead of Quarterly General Meetings, and also the organisation of
the Graduates' Section have taken place during the Presidency of Sir
William H. White, to whom so much of the success of these new and
important departures is due.

The work of the Graduates has been carried on with considerable
success. Seven monthly Meetings were held at the Institution in a
room fitted up especially for their accommodation. These Meetings
were usually presided over by a Member of Council, and the
following Papers were read :—

The Application of Hydraulic Power to Construction of Bridge and Girder
    Work; by Mr. H. M. Rootham.
Motor Haulage on Common Roads; by Mr. Alfred Marsden.
Works Management, Methods of Quick Production of Repetition Work; by Mr.
    W. B. Cleverly.
Treatment of Sewage and Sludge in Rural Districts; by Mr. H. H. Mogg.
The Manufacture of Heavy Mooring Chains; by Mr. Theodore Schontheil.
Steel Skeleton Construction, as applied to Buildings on the American System;
    by Mr. Brees van Homan.

A number of Visits were made by the Graduates to Works in
the neighbourhood of London, and the interest shown gave rise to
good discussions upon two Reports of these visits. The Council
have awarded prizes to Mr. W. B. Cleverly and Mr. Brees van
Homan for their Papers on "Works Management, Methods of
Quick Production of Repetition Work" and "Steel Skeleton
Construction, as applied to Buildings on the American System"
respectively. The prospects of building up a flourishing Graduates'
Section of the Institution are encouraging, and it is hoped this
movement will receive the assistance of all Members.

In consequence of a desire expressed by several Members of the
Institution, the Council communicated with the War Office in
February, asking if it would be of any advantage to the Government

to have the assistance in South Africa of the engineering experience of Members of the Institution.

The reply indicated the high appreciation of the Secretary of State for War, and stated that, although arrangements had already been made, the offer would certainly be borne in mind in case circumstances should alter.

The Council were requested by the Executive of the Glasgow International Engineering Congress to take an active interest in its success. After full deliberation and consultation with the officers of other Institutions, the Council have consented to take charge of the Mechanical Section of the Congress, the meetings of which will be held during the first week of September 1901. They have also decided that these arrangements should not interfere with the ordinary Summer Meeting of the Institution, which will be held during the last week in July at Barrow-in-Furness.

The Council have devoted considerable attention to the question of the future usefulness of the Institution, and Papers will shortly be submitted on Automatic Screw Machinery, Various Systems of Electric Traction, and on the Balancing of Locomotive Engines. Papers have been promised in connection with the Fencing of Machinery, the fixing of Standard Sizes for Rolled Sections and also for Steam- and other Pipe Flanges, all these being matters which are at present engaging the special attention of the engineering profession. The Council invite Members to assist them by preparing Papers on important and interesting subjects, and suggestions in connection with prospective Papers should be communicated to the Secretary.

The result of the ballot for the election of a President, two Vice-Presidents, and five Members of Council, to fill the vacancies caused by the usual retirements, will be announced at the Annual Meeting.

Dr.   ACCOUNT OF REVENUE AND EXPENDITURE

Expenditure.

	£	s.	d.	£	s.	d.
To Expenses of Maintenance and Management—						
Salaries and Wages	2,329	3	6			
Postages, Telegrams, and Telephone . . .	384	1	1			
Heating, Lighting, and Power . 138 9 6						
Do., amount outstanding . 27 3 3	165	12	9			
Fittings and Repairs . . . 39 6 11						
Do., amount outstanding . 12 0 0	51	6	11			
Housekeeping	132	5	4			
Petty Expenses	38	9	6			
				3,100	19	1
,, Printing, Stationery, and Binding—						
Printing and Engraving Proceed-						
ings 1,383 1 11						
Do., amount outstanding . 211 13 4	1,594	15	3			
Stationery and General Printing	417	8	10			
Binding	43	3	5			
				2,055	7	6
,, Rent, Rates, Taxes, &c.—						
Ground Rent	875	17	2			
Rates and Taxes	757	11	0			
Insurance	38	0	0			
				1,671	8	2
,, Meeting Expenses—						
Printing 315 9 6						
Reporting 43 19 2						
Diagrams 10 14 6						
Travelling and Incidental Expenses 120 11 3	490	14	5			
Do., amount outstanding	13	15	6			
				504	9	11
,, Books purchased				11	12	1
,, Research Expenses				163	10	9
,, Debenture Interest				1,000	0	0
,, Interest on Bank Loan				90	18	5
,, Special Expenses—						
Conversazione	165	9	8			
Dinner Expenses	81	1	4			
Graduates' Prizes	10	6	0			
Law Charges	3	3	0			
				260	0	0
,, Depreciation on Furniture and Fittings				65	15	8
				8,924	1	7
Less outstanding expenses at 1st Jan. 1900, already included						
in last year's accounts				328	10	6
				8,595	11	1
,, Balance, being excess of Revenue over Expenditure, carried to						
Balance Sheet				409	17	0
				£9,005	8	1

FOR THE YEAR ENDED 31st DECEMBER 1900.   *Cr.*

Revenue.

	£	s.	d.
By Entrance Fees	420	0	0
„ Subscriptions for 1900 7,703		0	0

	£	s.	d.	£	s.	d.
„ Subscriptions previously in arrear, paid during 1900	301	10	0			
Less estimated amount credited in last account	291	0	0			
				10	10	0
„ Subscriptions received in advance				90	0	0
„ Life Compositions				77	0	0
„ Interest, &c.—						
From Bank	6	0	10			
„ *Investments*	243	12	10			
Income Tax refunded	11	0	11			
				260	14	7
„ Reports of Proceedings—						
Extra Copies sold				142	3	6
„ Debenture Transfer Fees				0	10	0
„ Estimated value of subscriptions in arrear (*being equal to the amount received in* 1900)				301	10	0

£9,005 8 1

Dr.   BALANCE SHEET

		£	s.	d.

To Debentures—

250 of £100 each at 4%, redeemable in 1917, or at par at any date after 1st Jan. 1908, on six months' notice to holder   25,000   0   0

„ **Cash—**

	£	s.	d.	£	s.	d.			
Union Bank of London, overdraft	586	19	2						
Add cheque outstanding	27	1	6						
				614	0	8			
Less In the Secretary's hands				27	10	0			
							586	10	8

„ **Sundry Creditors—**

	£	s.	d.			
Loan from Union Bank of London	3,250	0	0			
Accounts owing, not yet rendered	264	12	1			
Willans Premium Fund	14	6	0			
Unclaimed Debenture Interest (coupons not presented)	96	6	9			
				3,625	4	10

„ **Capital of the Institution :—**

Set aside in 1897 and 1898 for redemption of Debentures   5,000   0   0

	£	s.	d.			
Balance at 31 December 1899	35,495	8	11			
Add Excess of Revenue over Expenditure for the year ended 31 December 1900	409	17	0			
				35,905	5	11

		£70,117	1	5

Signed by the following members of the Finance Committee :—

WILLIAM H. WHITE,
WILLIAM H. MAW,
E. B. ELLINGTON,
H. GRAHAM HARRIS.

AT 31st DECEMBER 1900. *Cr.*

	£	s.	d.
By Investments	6,859	4	8

£
4,237 *London and North Western Ry.* 3% *Debenture Stock*
3,945 12s. *Midland Railway* * 2½% „ „
1,000 *Consols* 2¾% *

The Market Value of these investments at 31st Dec. 1900 was about £8,716, of which £5,000 is reserved for redemption of Debentures.

		£	s.	d.
„ Subscriptions in Arrear, *estimated value (being equal to the amount received during* 1900)		301	10	0
„ Furniture and Fittings (*less depreciation*)		1,249	17	2
„ Books in Library, Drawings, Engravings, Models, Specimens, and Sculpture (*estimate of* 1893)		1,340	0	0
„ Amount in Union Bank to meet unclaimed Debenture Interest (*coupons not presented*)		96	6	9
„ Proceedings—stock of back numbers, *not valued.*				
„ Institution House, expenditure in previous years 59,214 0 7				
„ „ „ during 1900 . . 1,056 2 3		60,270	2	10

£70,117 1 5

* See page 8.

I certify that all my requirements as Auditor have been complied with, and I report to the Members that I have audited the above Balance Sheet, dated the 31st December 1900, and in my opinion such Balance Sheet is properly drawn up and exhibits a true and correct view of the state of the affairs of the Institution as shown by its Books.

ROBERT A. McLEAN, F.C.A.,
Auditor,

14th *January* 1901.   1 Queen Victoria Street, London, E.C.

WILLANS PREMIUM FUND.

Investment £159 8s. 5d. of India 3% Stock . . . . cost £165 5s. 0d.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Balance, held in trust .	14	6	0	By Interest, 1898 . .	4	15	4
				,, ,, 1899 . .	4	15	4
				,, ,, 1900 . .	4	15	4
	£14	6	0		£14	6	0

Audited, certified, and signed by the names on pages 14-15.

DECLARATION OF TRUST
OF THE WILLANS PREMIUM FUND.

To all to whom these presents shall come The Institution of Mechanical Engineers and The Institution of Electrical Engineers send greeting. Whereas a Fund has been subscribed by the friends of the late PETER WILLIAM WILLANS, of Thames Ditton, for the purpose of commemorating his name and the services which he rendered to Engineering and Electrical science; and at the request of the subscribers to the said fund the above-named Institutions have agreed to act as joint Trustees thereof, and the sum of One hundred and sixty-five pounds has accordingly been paid to the said Institutions: now these presents witness that the said Institutions do hereby declare the Trusts upon which they hold the said fund to be as follows :—

1. To invest the said fund upon such securities as trustees are by law authorised to hold, and in such names as the Councils of the two Institutions shall from time to time direct.

2. To apply the proceeds of the said investment as and when received, after payment of any expenses incidental to the

administration of the trust, to the Premium hereinafter described, to be known as "the Willans Premium."

3. The Willans Premium shall be awarded alternately by the Council of each of the above-mentioned Institutions ; and first by The Institution of Electrical Engineers in December 1897.

4. The Council of the awarding Institution in each alternate period shall award the Willans Premium for the best original paper communicated to their Institution, dealing with such a general subject as the utilisation or transformation of energy, treated especially from the point of view of efficiency or economy : provided that the Premium shall not be awarded unless a paper of sufficient merit in the judgment of the awarding Council shall have been so communicated since the preceding award of that Council.

5. The Premium shall be awarded triennially in and after December 1897, unless otherwise determined by resolution of the respective Councils of the two Institutions.

6. The Premium may be awarded either in money or books or medal, or in any other form which in the instance of any individual award the awarding Council may then determine.

7. In case of no award at the end of any triennial period, the premium available for that award shall be added to the capital of the fund.

In witness whereof The Institution of Mechanical Engineers have hereunto affixed their common seal, and the President and Secretary of The Institution of Electrical Engineers have hereunto set their hands, this sixteenth day of January 1895.

———

The Seal of The Institution of Mechanical Engineers was impressed by the President in the presence of Alfred Bache, Secretary ; and the document was signed as follows :—

ALEXANDER B. W. KENNEDY,
President of The Institution of Mechanical Engineers.
R. E. CROMPTON,
President of The Institution of Electrical Engineers.
F. H. Webb, Secretary of The Institution of Electrical Engineers.

LIST OF DONATIONS TO THE LIBRARY.

BOOKS (in order received).

Mémorial publié à l'occasion du Cinquantenaire de l'Institut Royal des Ingénieurs Néerlandais, 1847-1897; from the Institute.

Lubrication and Lubricants: a Treatise on the Theory and Practice of Lubrication, by L. Archbutt and R. M. Deeley; from Mr. R. M. Deeley.

Indicator Diagrams; Combustion of Fuel; from the author, Prof. W. W. F. Pullen.

Hydraulic Power Engineering, by G. Croydon Marks; from the publishers.

Plumbing and Sanitation, by G. B. Davis and F. Dye; from Mr. G. B. Davis.

Liverpool Water Works: Report of the Engineer, Part I; from Mr. Joseph Parry.

Some Typical Locomotives constructed from 1840-1852, being all Original Drawings or Tracings; from Mr. David Joy.

Relazione sull' andamento dei Servizi; from the Italian Minister of Public Works.

Automobile Club Show, Richmond, 1899: Judges' Report, etc.; from the Automobile Club.

Das Eisbrechwesen im Deutschen Reich, by M. Görz and M. Buchheister; Schiffswiderstand und Schiffsbetrieb (Text and Plates), by R. Haack; from the Prussian Government.

Report to the Seventh International Congress of Navigation, Brussels, July 1898, by E. L. Corthell; from the United States Government.

Law and Practice relating to Letters Patent for Inventions, by R. W. Wallace and J. B. Williamson; from the authors.

La Tour de Trois Cents Mètres (Text and Plates), by Gustave Eiffel; Travaux Scientifiques exécutés à la Tour de trois cents mètres de 1889 à 1900; from M. Gustave Eiffel.

Life of Sir James N. Douglass, F.R.S., by Thomas Williams; from Mr. W. T. Douglass.

La Navigation Internationale et ses Intérêts dans les Ports et les Canaux du monde, et les moyens pour leur amélioration, by L. W. Bates; from the author.

High Speed Steam Engines, by William Norris and B. H. Morgan; from Mr. William Norris.

Climatic conditions necessary for the Propagation and Spread of Plague, by Baldwin Latham; from the author.

Mathematical Drawing and Measuring Instruments, by W. F. Stanley; from the author.

Principles, Construction, and Application of Pumping Machinery, by Henry Davey; from the author.

Gas, Oil, and Air Engines (Third edition), by Bryan Donkin; from the author.

Water Supply of the City of New York; from the Merchants' Association of New York.

Ditto; from Mr. J. F. O'Connor.

Origin, Rise, and Progress of the Science of Geometry and Mathematics, by Prof. H. J. Spooner; from the author.

Workshop Mathematics (Parts 1 and 2); Elementary Practical Mathematics; from the author, Mr. Frank Castle.

Railed Roads: a Manual for Local Boards, etc., by F. J. E. Spring, C.I.E.; from the author.

Field Work and Instruments, by A. T. Walmisley; Land Surveying and Levelling, by A. T. Walmisley; Stresses and Strains, by F. R. Farrow; Structural Iron and Steel, by W. N. Twelvetrees; from "The Builder."

Atlas des Voies Navigables de la France, 1899; from the Minister of Public Works.

The following from Mrs. Barnes:—Drawings of the London and Birmingham Railway, 1839, by J. C. Bourne and John Britten; History and Description of the Great Western Railway, 1846, by J. C. Bourne; Illustrations of Mill Work and other Machinery (Atlas), 1841, by George B. Rennie; Iron Bridge Construction (Vol. II, Plates), 1861, by William Humber; Public Works of Great Britain 1838, by F. W. Simms; Tafeln zur Theorie und zum Bau der Turbinen und Ventilatoren, 1844, by F. Redtenbacher.

The following from Mr. Henry Chapman:—British South Africa Co.: Reports on Administration of Rhodesia, 1897–98; Information as to Mining in Rhodesia, 1900; Compagnie des Forges et Aciéries de la Marine et des Chemins de fer: Artillerie (Système Darmancier et Dalzon); Usines de la Compagnie; Note sur les Établissements de la Compagnie; Exposition de 1900; Matérial de Guerre, by M. Darmancier.

Association des Maîtres de Forges de Charleroi: Rapport Général sur la Situation de l'Industrie Métallurgique en 1899; from the Association.

The following Official Publications from the Government of New South Wales:— Annual Report of the Railway Commissioners for the year ending 30 June 1900; Report of the Department of Public Works for the year ended 30 June 1899; Annual Report of the Department of Mines and Agriculture, 1898; Wealth and Progress of New South Wales, 1897–98 and 1898–99, by T. A. Coghlan; New South Wales Contingents to South Africa, 1899–1900.

Gold-Fields of Victoria, Monthly Returns; Gold Mining Statistics, 1898; Geological Survey of Victoria, Monthly Progress Report; from the Chamber of Mines, Victoria.

Report of the Department of Mines, 1899; Supplement to Government Gazette of Western Australia; Eleventh Financial Statement of the Right Hon. Sir John Forrest, P.C., K.C.M.G., Premier and Colonial Treasurer, Western Australia, 9 October 1900; from the Government of Western Australia.

The following from the U.S. Geological Survey:—Nineteenth Annual Report, Parts II, III, and V (with Atlas), 1897–98; Twentieth Annual Report, Parts I, VI, and VI continued, 1898–99; Monographs, XXXII (Part II), XXXIII, XXXIV, XXXVI, XXXVII, and XXXVIII; Bulletins, 150–162.

The following from California University, U.S.:—International Competition for the Phoebe Hearst Architectural Plan for the University of California; Annual Report of the Secretary, 1897; Bulletin of Geology, Vol. II, Nos. 5 and 6; California University Chronicle, Vol. II, Nos. 1–6; Register, 1898–99.

Appendix to the Annual Report on the Inspection of Mines in India, 1898, by James Grundy; from the India Office.

PAMPHLETS, &c.

American Trade with Siam: Report by the Philadelphia Commercial Museum; The World's Commerce and the United States' share of it; The American Merchant Marine compared with that of other countries; Asphaltum; from the Philadelphia Museum.

Combustion and Forced Draught, with special reference to Smoke Prevention; Machines and Tools for working Sheet Metals; The Meldrum Furnace; from the author, Mr. R. B. Hodgson.

Engineers and their Institutions: Address read by the President of the Gloucestershire Engineering Society; from Mr. J. W. Howard, President.

Copyright and Patent Laws of Japan, Vol. II, 1899; from Mr. W. Silver Hall.

Experiments on the Thrust or Lifting Power of Air Propellers, by P. Y. Alexander; from the author.

Horsfall Destructors; Report by Lord Kelvin and Prof. Archibald Barr.

Boilers for Low-pressure Hot-water Heating, by Sam Naylor; from the author.

Steam Transport on Roads, by Lt.-Col. Templer; from Mr. T. L. Aveling.

Relative advantages of Ordinary and Compound Locomotives, by C. E. Wolff; from the author.

Corporation Electric Lighting Accounts; from the London Chamber of Commerce.

Stoddart's Improved Sewage Filter, by F. W. Stoddart; from "The Public Health Engineer."

Report of the Hydraulic Engineer on the Water Supply of Queensland, 1899; from Mr. J. B. Henderson.

L'Échappement et le Tirage dans les Locomotives ; Rapport sur un Compresseur d'Air à deux phases ; from the author, M. Edouard Sauvage.

Chemins de fer de l'Ouest : Notice sur le Matériel, les Objets et les Dessins présentés à l'Exposition Universelle de 1900 ; from M. Edouard Sauvage.

Description, Method of Operation, and Maintenance of the Vauclain System of Compound Locomotives ; from the publishers.

Bathymetrical Survey of the Fresh-water Lochs of Scotland, by Sir John Murray, K.C.B., and F. P. Pullar ; from Mr. F. P. Pullar.

Distribution of Pressure due to Flow round Submerged Surfaces, with special reference to Balanced Rudders, by Prof. H. S. Hele-Shaw, LL.D., F.R.S.; from the author.

Liverpool Trials of Motor Vehicles for Heavy Traffic, 1898 : Judges' Report; from Prof. H. S. Hele-Shaw, LL.D., F.R.S.

The Viagraph : a New Instrument for Testing Road Surfaces, by J. Brown ; from the author.

Foundry Iron, by Herbert Pilkington ; from the author.

Address of the President of the South Wales Institute of Engineers ; from Mr. Thomas Evens, President.

Gutachten über die Abnahme-Versuche vom Januar 1900 an einer 1,000 Kilowatt-Dampfturbine und Alternator von C. A. Parsons and Co., by W. H. Lindley, M. Schrötter, and H. F. Weber; from Mr. W. H. Lindley.

Presidential Address to the Glasgow and West of Scotland Technical College Scientific Society ; from Mr. D. H. Morton, President.

Increasing Productiveness of Labor : a result of Invention, by F. H. Richards; from the author.

Purification of the Feed Water of Locomotives and the use of Disincrustants : Report to the International Railway Congress, Paris, 1900, by John A. F. Aspinall ; from the author.

Most Recent Works at some of the principal British Seaports and Harbours, by L. F. Vernon-Harcourt ; from the author.

Review of the American Standard Specifications, &c., adopted by the Members of the International Association for Testing Materials (also French translation and German abstract), by A. L. Colby ; from the author.

Electrical Distribution in Cities, by T. L. Miller; from the author.

Experiments made with the Bashforth Chronograph : Second Supplement to a revised account, by F. Bashforth ; from the author.

A Page of History in Cotton Spinning, by Prof. Th. Gebauer (translated by Oscar S. Hall); from the translator.

Disposal of House Refuse in Bradford, by John McTaggart; from the author.

Die Berechnung der Zentrifugalregulatoren, by Prof. J. Bartl; from the publisher.

Discoverers of Iron and Steel; Scope of the Small Converter in Steel Foundry Practice; from the author, Mr. E. F. Lange.

Nature and Yield of Metalliferous Deposits, by B. H. Brough; from the author.

Piece-Work, by C. W. Hill; from the author.

Utilisation directe des Gaz de Hauts-Fourneaux pour la Production de la Force Motrice, by H. Hubert; from the Société Anonyme John Cockerill.

Fondation Nobel: Statut et Règlements; from the Board of Education, London.

Failures in Draw- and Buffing-Gear in Railway Wagons, by G. T. Glover; from the author.

Il Tiraggio artificiale dei Focolari; La Fabbricazione del Ghiaccio col sistema Holden; from the author, Signor A. Pacchioni.

Report of the Kew Observatory Committee, 1899; from the National Physical Laboratory.

Report of the Tunbridge Wells Borough Electrical Engineer for the year 1900; from Mr. H. L. P. Boot.

Municipal Public Works, by Ernest M'Cullough; from the author.

Gas Engineers' Pocket Almanack, 1900; from Messrs. W. Sugg and Co.

Engineers' and Surveyors' Compendium and Diary, 1900; from the editor.

List of Chinese Lighthouses, Light-vessels, Buoys and Beacons, 1900; from the Inspector-General of Chinese Customs.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Report to the Governors of the City and Guilds of London Institute, March 1900; from the Institute.

Crystal Palace Engineering School Magazine; Old Students' Society, Annual Report, 1899–1900; from Mr. J. W. Wilson.

Correspondence in the matter of the Society of Arts and Henry Wilde on the award to him of the Albert Medal, 1900; from Dr. Henry Wilde.

Fifth Annual Report, 1899, of the John Crerar Library, Chicago; from the Library.

Notes et Observations sur l'Emploi de la Vapeur comme Puissance Motrice; Etude sur Divers Gaz Combustibles utilisés pour divers usages industriels en général, et principalement pour la production de la force motrice; from the author, M. A. Lencauchez.

Year-Book of the Royal Society, 1900; Reports to the Malaria Committee, 1899–1900 and 1900; from the Royal Society of London.

Rede zur Feier der Jahrhundertwende in der Halle der Königlichen Technischen Hochschule zu Berlin, 9 Januar 1900; from the Rector.

Register of the Institute of Chemistry of Great Britain and Ireland, 1900–1901; from the Institute.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 December 1899 and 30 June 1900; from the Registrar.

City and Guilds Technical College, Finsbury, Programme 1899-1900; from the College.

Calendars 1900–1901 from the following Colleges:—Royal Technical High School, Berlin; Mason University College, Birmingham; University College, Bristol; King's College, London; City of London College; Royal Technical High School, Munich (with Report); University College, Sheffield; and Civil Engineering College, Sibpur.

Lockwood's Builder's, Architect's, Contractor's and Engineer's Price Book, 1900 ; from the publishers.

Electrical Trades' Directory and Handbook, 1900; from the publishers.

Universal Directory of Railway Officials, 1900; from the publishers.

The following Abridgments of Specifications of Patents for Inventions, 1893–96 :—44, 58, 69, 78–84, 87–88, 91, 94–97, 99–119, 121–131, 133–135, 137–141, 143, 145–146; Subject List of Works on Photography in the Patent Office Library; Ditto of Works on Laws of Industrial Property; from the Patent Office.

PHOTOGRAPHS.

Sky Line of New York : Battery to Post Office; from Mr. Gus. C. Henning.

Eight w.c. Engine for the Imperial Government Railway of Japan (photograph and blue print); from Mr. R. F. Trevithick.

Illustrations of Astronomical Instruments by Messrs. Warner and Swasey ; from Mr. Ambrose Swasey.

CATALOGUES.

Baldwin Locomotive Works, Records of Recent Construction, Nos. 17–20, 1900; from the Company.

Mathematical Instruments, 1899; from Mr. W. F. Stanley.

Machinery and Tools; from Messrs. C. Churchill and Co.

List of Warming and Ventilating Works; from Messrs. Ashwell and Nesbit.

Wrought-iron Cement-lined Conduits for Electrical Subways ; from the National Conduit and Cable Co.

Section-book of Steel Joists, etc.; from Messrs. Redpath, Brown and Co.

Steel Ropes, Appliances, Ropeways ; from Messrs. Bullivant and Co.

Steel and Iron Wire Ropes ; from Messrs. G. Cradock and Co.

Cranes, etc. ; from Messrs. Jessop and Appleby Brothers.

The following PUBLICATIONS from the respective Societies and authorities:—
British Isles.

British Association for the Advancement of Science ; Report.

British Fire Prevention Committee.

Chesterfield and Midland Counties Institution of Engineers ; Transactions.

Civil Engineers, The Institution of ; Proceedings.

Cleveland Institution of Engineers, Middlesbrough ; Proceedings.

Cycle Engineers' Institute, Birmingham ; Proceedings.

Electrical Engineers, Institution of ; Journal.

Engine, Boiler, and Employers' Liability Insurance Company, Manchester ;
    Report (from Mr. Michael Longridge).

Engineers and Shipbuilders in Scotland, Glasgow, Institution of ; Transactions.

Incorporated Gas Institute ; Transactions.

Iron and Steel Institute ; Journal.

Junior Engineers, Institution of ; Transactions.

Literary and Philosophical Society of Manchester ; Proceedings.

Liverpool Free Public Library ; Forty-seventh Annual Report.

Manchester Association of Engineers ; Transactions.

Manchester Geological Society ; Transactions.

Manchester Steam Users' Association ; Reports.

Midland Institute of Mining, Civil and Mechanical Engineers, Barnsley ;
    Transactions.

Mining Engineers, Institution of, Newcastle-on-Tyne ; Transactions.

Mining Institute of Scotland, Hamilton ; Transactions.

Naval Architects, Institution of ; Transactions.

North of England Institute of Mining and Mechanical Engineers, Newcastle-
    on-Tyne ; Transactions.

North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne ;
    Transactions.

Patent Agents, Chartered Institute of ; Transactions.

Physical Society of London ; Proceedings.

Radcliffe Library, Oxford ; Catalogue of Additions during 1899.

Royal Agricultural Society of England ; Journal.

Royal Cornwall Polytechnic Society, Falmouth ; Report.

Royal Dublin Society ; Transactions and Proceedings.

Royal Engineers' Institute, Chatham ; Professional Papers.

Royal Institute of British Architects ; Transactions and Journal.

Royal Irish Academy, Dublin ; Transactions and Proceedings.

Royal Society of Edinburgh ; Proceedings.

Royal Society of London ; Philosophical Transactions (A) and Proceedings.

Royal United Service Institution; Journal.
Science Abstracts—Physics and Electrical Engineering.
Society of Arts; Journal.
Society of Chemical Industry; Journal.
Society of Engineers; Transactions.
South Staffordshire Institute of Iron and Steel Works Managers, Dudley;
    Proceedings.
South Wales Institute of Engineers, Cardiff; Proceedings.
Surveyors' Institution; Transactions and Professional Notes.
Waterworks Engineers, British Association of; Transactions.
West of Scotland Iron and Steel Institute, Glasgow; Journal.

Austria.

Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, Vienna.
Zprávy spolku Architektův a Inženýrů v království českém, Prague.

Belgium.

Académie Royale de Belgique, Brussels; Bulletin.
Association des Ingénieurs sortis des Écoles spéciales de Gand; Annales.
International Railway Congress (English edition), Brussels; Bulletin.

Canada.

Canadian Society of Civil Engineers, Montreal; Transactions.

France.

Académie des Sciences, Paris; Comptes Rendus des Séances.
Annales des Mines, Paris.
Association Technique Maritime, Paris; Bulletin.
Conservatoire des Arts et Métiers, Paris; Annales.
Ponts et Chausées, Paris; Annales.
Revue Maritime, Paris.
Société d'Encouragement pour l'Industrie Nationale, Paris; Bulletin.
Société Industrielle de Mulhouse; Bulletin.
Société Industrielle du Nord de la France, Lille; Bulletin.
Société Industrielle de Rouen; Bulletin.
Société des Ingénieurs Civils de France, Paris; Bulletin.
Société Scientifique Industrielle de Marseille; Bulletin.

Germany.

Zeitschrift für Architektur und Ingenieurwesen, Hannover.
Zeitschrift des Vereines deutscher Ingenieure, Berlin.

Holland.

Tijdschrift van het Koninklijk Instituut van Ingenieurs, 'sGravenhage.

India.

Asiatic Society of Bengal, Calcutta; Proceedings and Journal.

Italy.

Associazione fra gli Utenti de Caldaie a Vapore nelle Provincie Napolitane ;
    Rapporto dell' Ingegnere Direttore.
Reale Istituto d'Incorraggiamento di Napoli ; **Atti**.
Società degli Ingegneri e degli Architetti Italiani, Rome ; Annali.

Japan.

Japan Society of Mechanical Engineers, Tokyo ; Journal.

New South Wales.

Engineering Association of New South Wales; Proceedings.

Norway.

Teknisk Ugeblad, Christiania.

Sweden.

Geological Institution of the University of Upsala; Bulletin.
Svenska Teknologföreningen, Stockholm.

Switzerland.

Bulletin Technique, Geneva.
Société Vaudoise des Ingénieurs et des Architectes, Lausanne; **Bulletin**.

Transvaal.

South African Association of Engineers and **Architects,** Johannesburg
    Proceedings.

United States.

American Institute of Mining Engineers, New York; **Transactions.**
American Philosophical Society, Philadelphia; **Transactions and Proceedings.**
American Society of Civil Engineers, New York; **Transactions and Proceedings.**
American Society of Mechanical Engineers, New York; **Transactions.**
Association of Engineering Societies, Philadelphia ; **Journal.**

Franklin Institute, Philadelphia ; Journal.
School of Mines Quarterly, Columbia College, New York.
United States Artillery, Fort Monroe ; Journal.
United States Naval Institute, Annapolis ; Proceedings.
United States Patent Office Gazette, Washington.
Western Society of Engineers, Chicago ; Journal.

The following PERIODICALS from the respective Editors :—

British Isles.

Appointments Gazette.
Arms and Explosives.
The Autocar.
Automotor and Horseless Vehicle Journal.
The British Architect.
British Invention.
British Refrigeration.
The Builder.
Builders' Journal and Architectural Record.
Camera Club Journal.
Cassier's Magazine.
Cold Storage and Ice Trades Review.
The Colliery Guardian.
The Contract Journal.
The Cyclist.
Domestic Engineering.
The Electrical Engineer.
The Electrical Review.
The Electrician.
The Engineer.
The Engineer and Iron Trades' Advertiser.
Engineering.
The Engineering Magazine.
Engineering Times.
Engineers' Gazette.
Feilden's Magazine.

The Fireman.
Hardware, Metals and Machinery.
Ice and Cold Storage.
The Journal of Gas Lighting.
Invention.
Inventors' Review.
The Iron and Coal Trades Review.
Iron Trade Circular, Ryland's.
The Ironmonger.
Ironmongery.
Lightning.
Locomotive Magazine.
London Technical Education Gazette.
The Machinery Market.
The Marine Engineer.
The Mariner.
The Mechanical Engineer.
Mechanical Progress.
The Mechanical World.
Midland Counties Herald.
The Mining Journal.
Model Engineer and Amateur Electrician.
Phillips' Monthly Machinery Register.
Motor Car Journal.
The Plumber and Decorator.
The Practical Engineer.
Property Gazetteer.
The Public Health Engineer.

The Railway Engineer.
The Quarry.
The Shipping World.
The Steamship.
The Surveyor.

The Textile Recorder.
Trade and Industry.
Transport.
Water.

Belgium.

De Ingenieur.

Revue Universelle des Mines.

France.

L'Industrie.

Revue générale des Chemins de fer.

Germany.

Glaser's Annalen.

Stahl und Eisen.

India.

The Indian and Eastern Engineer.
Railways.

Indian Textile Journal (English edition).

Italy.

Giornale del Genio Civile.

Spain.

El Ingeniero Español (London edition).

United States.

American Machinery.
American Machinist.
American Manufacturer.
Electrical Review.
Electrical World and Engineer.
Electricity.
The Engineering and Mining Journal.

Engineering News.
The Engineering Record.
Engineering Review.
Marine Review.
The Railway and Engineering Review.
Railway Master Mechanic.
Street Railway Journal.

The PRESIDENT, in moving the adoption of the Report, invited remarks upon it from the members.

No remarks being offered, the Report was unanimously adopted.

The PRESIDENT said he had the pleasant duty, on behalf of the Institution, of making the Presentation of the Willans Premium to Captain H. Riall Sankey, and of the prizes given to the authors of the selected papers read before the Graduates' section. In both those instances, he said, the Institution was making new departures, but it was hoped that in future there would be more and more examples in that direction. With regard to the Willans Premium, the conditions were that the papers to be considered in assigning the prizes were those which dealt with "such a general subject as the Utilisation or Transformation of Energy, treated especially from the point of view of efficiency or economy"; and it was thoughtfully provided that the Premium should not be awarded unless a paper of sufficient merit in the judgment of the awarding Council should have been so communicated. The members would understand that the Council had no difficulty in this latter point; and they would all feel that there was a most peculiar fitness in the fact that the first award of the Willans Premium by this Institution had been made to a gentleman of the high scientific ability of Captain Sankey, whose association with the late Mr. Willans and the work he did was well known.

The PRESIDENT then presented the Premium to Captain Sankey.

The PRESIDENT next had the pleasure of presenting the prizes to the two members of the Graduates' section. In doing so, he said that the Council shared with him the belief that recent developments of the Graduates' section, which had been made possible by entering into the new House of the Institution, must have a most important effect upon the welfare and growth of the Institution in the time to come.

The PRESIDENT then presented prizes to Mr. W. B. Cleverly and Mr. Brees van Homan.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected :—

PRESIDENT.

WILLIAM H. MAW, ...   London.

VICE-PRESIDENTS.

ARTHUR KEEN, ...   Birmingham.
T. HURRY RICHES, ...   Cardiff.

MEMBERS OF COUNCIL.

SIR J. WOLFE BARRY, K.C.B., LL.D., F.R.S.,   .   London.
WILLIAM DEAN, ...   Swindon.
BRYAN DONKIN, ...   London.
H. GRAHAM HARRIS, ...   London.
A. TANNETT-WALKER, ...   Leeds.

For supplying the vacancy amongst the Vice-Presidents caused by the election of Mr. Maw as President, the Council had appointed Mr. BRYAN DONKIN as a Vice-President for the present year; and for supplying the consequent vacancy amongst the Members of Council, the Council had appointed Sir W. THOMAS LEWIS, Bart., as a Member of Council for the present year, his name being the next highest in the voting for the election at this Meeting. Agreeably with the Articles of Association, both these gentlemen would retire at the next Annual General Meeting, and would be eligible for re-election.

The Council for the present year is therefore as follows :—

PRESIDENT.

WILLIAM H. MAW, ...   London.

PAST-PRESIDENTS.

SIR LOWTHIAN BELL, BART., LL.D., F.R.S.,   .   Northallerton.
SIR FREDERICK J. BRAMWELL, BART., D.C.L.,
     LL.D., F.R.S., ...   London.
SIR EDWARD H. CARBUTT, BART.,   .   .   .   London.

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ALEXANDER B. W. KENNEDY, LL.D., F.R.S., . London.
E. WINDSOR RICHARDS, ... Caerleon.
JOHN ROBINSON, ... Leek.
PERCY G. B. WESTMACOTT, ... Ascot.
SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc.,
    F.R.S., ... London.

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EDWARD P. MARTIN, ... Dowlais.
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SIR THOMAS RICHARDSON, ... Hartlepool.
A. TANNETT-WALKER, ... Leeds.
JOHN I. THORNYCROFT, F.R.S., . . . London.

The PRESIDENT said that, before he fulfilled his last duty as President and asked his successor to occupy the Chair, there were a few words he would like to say. The last two years had been years of great and increasing success in the history of the Institution. The increase in membership had approached five hundred in two years, and had been equal to the growth that took place in the four or five years preceding. That evening the members had the pleasure of having a record number of further candidates elected, one hundred and twenty having been balloted for and entered in the books of the Institution. On the side of finance the results had been equally satisfactory. In going into the new House there were great and special expenses, but a point had been reached at which, as would be seen from the Report, expenditure was more than met by revenue, and it was possible to look forward, with greater numbers, to growing usefulness accompanied by a very satisfactory state of finance. The experiment made in the way of monthly meetings, he thought, must be admitted to be an unqualified success. The standard of the papers that had been read did not require a word from anyone, and the character of the discussions had certainly been excellent. The only difficulty that the Chairman had was to bring the discussions to a close within a reasonable time. If he had listened to the Secretary on more than one occasion the members would have been in the room until midnight; but he did not yield to the temptation, and that had led to the development of what with proper care and judgment was undoubtedly a valuable element in the Proceedings—the addition of written contributions to the discussions. There was another point which was not mentioned in the Report, but which his colleagues on the Council thought with him ought to receive attention from the Institution. It was that the publication of the Proceedings had been brought up close to date, which was a very satisfactory result, and had involved a large amount of work and reflected the greatest credit on the Secretary. As to the Graduates' section, whatever the wish may have been, it had not been possible to do much until the Institution was in its own home; but one of the first things that was considered and arranged when the House was occupied was how to give to the Graduates all

the help possible. He was confident that it was the desire of the Council and of the members that that side of the work of the Institution should be developed. There was a way in which the members of the Institution might help greatly, because although the meetings were organised by the Graduates themselves, conducted by a Committee of Graduates, and the business of that section was admirably worked by an Honorary Secretary of the section, Mr. Martin G. Duncan, himself a Graduate, yet still the Graduates would welcome any assistance that might be given by members who would either attend the meetings or give them facilities for visiting works, or in any other ways help their cause.

During the last year it had not been within his power to do all that he would have wished as President of the Institution. In the year that went before, he thought he might claim not to have spared himself in the interests of the Institution, and he would ask the members to believe that he had left nothing undone within his power to further the welfare of the Institution. He very much regretted that when the London Meeting took place he was on the Continent, necessarily absent, and therefore unable in any way to assist in entertaining the visitors; but he thought it was right that he should publicly express the feeling of gratitude which he had to his colleagues on the Council and to others, who by their work made that gathering such a conspicuous success. The Institution had received a beautiful engrossed and illuminated acknowledgment from the American Society of Mechanical Engineers of their sense of the honour which was done them during that visit.

The Address, which has been reproduced on Plate 18, reads as follows :—

To the President, Council, and Members of
  The Institution of Mechanical Engineers.
        Greeting :
    We, the President, Council, and Members of the American Society of Mechanical Engineers, in earnest appreciation of the warm hospitality extended to us by your Institution, do hereby extend this official acknowledgment.

                                                    E

(The President.)

Not only by the distinguished manner in which the American visitors were included at the recent professional sessions of your Institution, but also because of the hearty and cordial hospitality extended at all the social functions of the occasion, was the meeting of the Institution of Mechanical Engineers made memorable to us.

Coming at a time when international ties were doubly strong, because of stirring events in other parts of the world, these occasions of reunion and friendship between men of one blood and one profession have renewed and strengthened the bonds which everywhere unite men of the English-speaking race.

Therefore, seeing in your brilliant hospitality and notable reunions the expression of spontaneous good-will and fellowship toward the members of our Society : and still further perceiving in it powerful evidence of the ever-growing unity of thought and action between England and America, we feel ourselves deeply honoured in expressing for our Society the high appreciation which we feel.

Accept therefore this official expression, as but the formal statement of a heartfelt greeting, with wishes of happiness and prosperity, personal, professional, and national.

For the American Society of Mechanical Engineers,
New York, November 7th, 1900.

Seal of the Society.

CHARLES H. MORGAN, President.
F. R. HUTTON, Secretary.

The PRESIDENT in saying good-bye to the members as President, said he did so with a very full heart. He was sure everyone wished success to the Institution, and felt that in the new President they had a gentleman who would do much to ensure that success. No one had worked harder or more faithfully for the Institution for many years past than the new President. Those members who knew what he had done in the inner working of the Institution, in his attendance at Councils and Committees and devotion to the business of the Institution, felt sure that in his hands the future of the Institution was safe, and that he would do it honour in acting as its President and regulating its affairs.

Mr. WILLIAM H. MAW, on taking the chair as PRESIDENT, thanked the Members most heartily for the honour they had done him in electing him as President, and assured them that he appreciated the honour most thoroughly, and also appreciated its responsibilities. In his own case he could not help feeling that those responsibilities were very materially increased by the fact that he followed one who had carried out the duties of the Presidential chair so perfectly as Sir William White had done. He felt also that they were further increased by the remarks which Sir William White had kindly made, and which he feared might raise expectations which would be very difficult for him to fulfil. He had, however, the satisfaction of knowing that in the past the Presidents had always received not only the most cordial assistance from their fellow members of Council and the staff of the Institution, but also the most loyal support from all classes of members. He had every hope that such assistance and such support would be extended to him, and thus aided he trusted it would be in his power to carry on the duties of President, and to maintain during his term of office the influence and prestige of the Institution.

He could assure the members that it would be his most earnest endeavour to secure that end, and he hoped that when he gave up his office the members would feel that he had done his best on their behalf.

Dr. ALEXANDER B. W. KENNEDY, Past-President, said he did not think he ever spoke to the Institution of Mechanical Engineers with greater pleasure than he did at that moment, in asking the members to pass a very cordial vote of thanks to what he supposed he must now call the late President, Sir William White, for the manner in which he had fulfilled his duties during his Presidency. He was present at a Council Meeting more than a year ago when it was urged on Sir William that, if possible, he should undertake the second year's Presidency; and it was with a great deal of reluctance that Sir William accepted it. With how much care and personal trouble on his part, in spite of the national work which he had always in hand and in spite of a good deal of ill-health, he had

(Dr. Alex. B. W. Kennedy.)

done that work the members knew as well as he did, and they knew how much they were indebted to him for the success of the Institution during the past two years. The increase in the number of the Meetings of the Institution—the inauguration of the monthly meetings, and the pressing forward of the importance of the Graduates' section of the Institution—had been carried through under Sir William White's Presidency, and very greatly through his personal interest and trouble ; and for those developments in the working of the Institution he was certain the members would always be thankful, and would always connect with them Sir William White's name. For, although no doubt the very large attendance present that evening, compared with what was present a few years ago when he had the pleasure of being the President, was due to the greater personal popularity of the late and the new Presidents, yet still he was sure that a good deal of it must be also due to the way in which the interest of all the members of the Institution had been increased by the more vigorous manner in which the Council, with the President at its head, had pushed forward the proper work of the Institution. He was very glad to congratulate both the members and Sir William on having chosen as his successor his old friend—and he had no doubt he might say their old friend—Mr. Maw.

Mr. T. HURRY RICHES, Vice-President, had the great pleasure of seconding the vote of thanks, and was quite sure the members appreciated all that Professor Kennedy had said, and appreciated also most heartily the thoroughly good work which Sir William White had done for the Institution. It was an honour to any Institution to have such a man at its head. They looked to men such as Sir William White to be the beacon lights of the rising generation, and to form or create a model for that generation, because it must be a very strong incentive to the younger members to feel that there was something to aim for, a great position to acquire, a great name to earn, and a very glorious recollection to be established with those who, like Sir William White, had done so well and ably in their profession. So far as he himself was concerned, although he could very inadequately express what he felt, there was no one who had a

higher appreciation of Sir William White's abilities than he had himself. Sir William had extended to all who had anything to do with them the most kindly courtesy at all times and at all places, and it was an honour to place such men at the head of so great an Institution as that of the Mechanical Engineers. The members had all felt very deep sympathy with Sir William when he was stricken with illness last year; they mourned his absence and they mourned it because he had suffered, and no doubt suffered intensely. Today he was glad to see that although not quite his old self, Sir William was yet a great deal better than he had been, and he hoped he might be long spared, and that as each year came round for many years to come his health would improve and his happiness in life be further established.

The PRESIDENT, in putting the resolution to the meeting, said it was a great pleasure to him that the first motion with which he had to deal was one with which he so cordially agreed. He was sure the members would all endorse the terms used by Dr. Kennedy and Mr. Hurry Riches in proposing and seconding the vote, and he asked the members to carry it with acclamation.

The resolution was carried with applause.

Sir WILLIAM H. WHITE in responding, thanked the members most heartily for the recognition they had expressed of his endeavour to serve the Institution. He wished again to express his sense of gratitude to his colleagues on the Council for the manner in which they had assisted him in the work of the Institution, and he should like to include the Secretary and all those on the staff in his thanks. Of course one was more or less a figure-head in taking such a position as that of President—although he did not think it was only as a figure-head that a President was required, and his successor was well aware of that—but behind the President there must be always a Council working cordially with him, and a capable staff working hard, if the affairs of the Institution were to flourish. He was sure in saying Good-bye as President he left all those conditions amply fulfilled, and that the Institution would go

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(Sir William H. White.)

on and prosper, and in years to come there would have to be an
enlargement of the House, if all that was hoped for the Institution
should be fulfilled.

The PRESIDENT reminded the members that at the present
meeting the appointment had to be made of an Auditor for the
current year.

Mr. J. EMERSON DOWSON moved :—" That Mr. Robert A. McLean,
F.C.A., of 1 Queen Victoria Street, London, E.C., be re-appointed to
audit the accounts of the Institution for the present year at the same
remuneration as last year, namely, Twenty-five Guineas."   He
thought the members all knew that the accounts of the Institution
were kept in a very exemplary manner, but it was nevertheless
necessary that their accuracy should be certified by an independent
auditor.

Mr. WILLIAM H. FOWLER seconded the motion, which was carried
unanimously.

The Discussion was resumed on Mr. Humphrey's Paper on
" Power-Gas and large Gas-Engines for Central Stations," which had
been adjourned from the December Meeting.

The PRESIDENT announced that, as the Discussion had not been
concluded, an Extra Meeting would be held early in February.

The Meeting terminated at a Quarter to Ten o'clock.   The
attendance was 223 Members and 130 Visitors.

The Institution of Mechanical Engineers.

PROCEEDINGS.

8th February 1901.

An Extra Meeting was held at the Institution on Friday, 8th February 1901, at Eight o'clock p.m. ; William H. Maw, Esq., President, in the chair.

Before proceeding to business, the President said that since the Institution last met, a great national loss had been sustained, a loss which was quite unparalleled in the history of our time, and one which would long cast its shadow over the new century. By the death of our beloved Queen, there had been taken from them one who, not only by her wisdom and by her earnest devotion to her duty, had earned the respect and admiration of all the civilised nations, but one who by her perfect womanliness—he knew of no more expressive term—had drawn to herself the devoted love of all her subjects in every part of her vast Empire. He had said that the loss was an unparalleled one, but it had been alleviated by the knowledge that Her Late Majesty was succeeded on the Throne by one who long ago earned their respect and most sincere esteem, and one to whose reign they could look forward with the most loyal confidence. The Council had felt assured that the Members would desire that evening to put on record their most heartfelt sympathy with His Majesty and the Royal Family. An Address* had therefore been drafted, which he would read, and which he would ask the Members to receive and accept standing and in silence :—

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* The Address has been reproduced on Plate 19.

To the King's Most Excellent Majesty.

May it please Your Majesty,

The President, Council, and Members of the Institution of Mechanical Engineers, at this their first Meeting held since the death of Her Gracious Majesty Queen Victoria, desire to express their high appreciation of Her most noble life and their profound sympathy with Your Majesty and the Members of the Royal Family.

The Council and Members also desire to offer their dutiful and most hearty congratulations on Your Majesty's Accession to the Throne.

Your Majesty's interest in Engineering Achievements has been shown on many occasions, and has been evidenced by Your Gracious acceptance eleven years ago of the Honorary Membership of this Institution. The progress of mechanical invention has been a conspicuous feature of the long reign of our late revered Queen, and they trust that Engineering Science will continue to progress under Your Majesty's fostering care.

They pray that the blessings of health, long life, prosperity, and happiness, may be vouchsafed to Your Majesty and to Your august and beloved Consort, Queen Alexandra.

Seal
of the
Institution.

WILLIAM H. MAW, *President.*

EDGAR WORTHINGTON, *Secretary.*

8th February 1901.

The Minutes of the previous Meeting were read and confirmed.

The Discussion was resumed and concluded on Mr. Humphrey's Paper on " Power-Gas and large Gas-Engines for Central Stations."

The Meeting terminated at Ten o'clock. The attendance was 114 Members and 66 Visitors.

POWER-GAS AND LARGE GAS-ENGINES
FOR CENTRAL STATIONS.

BY MR. HERBERT A. HUMPHREY, *Member*, OF NORTHWICH.

During the next few years the design and erection of large central power-stations for the generation and distribution of electric energy in bulk promise to be the most important and interesting problem, with which mechanical engineers in this country will have to deal. The new stations will not only be larger than any now existing, but every possible effort will be made to reach a degree of economy in the production of power, such as will surpass any previous results.

Central-station work in this country, so far as magnitude of the undertakings is concerned, is undoubtedly behind when compared with American and Continental practice ; but the future development promises to be on an unparalleled scale, as indeed it must be if the rapidly growing requirements for lighting, traction, and general power are to be met. Although it is not probable that in the next few years London, for instance, will be able to show the enterprise of New York, which has in hand the construction of three power-stations, where in each case the maximum capacity will exceed 70,000 H.P., yet London has its 20,000 H.P. station at Bankside, its 10,000 H.P. at Deptford, and its 7,000 H.P. at Willesden, besides several stations running the latter rather close. Then in the provinces Manchester is erecting its 100,000 H.P. station, which, when carried to completion, will leave Edinburgh, Liverpool, Glasgow, and Brighton, which are the next largest, a long way behind. There are however some schemes for supplying electricity " in bulk," recently considered by a Select Parliamentary Committee, which may be the beginning of even greater things ; and it is to be

hoped that the short-sighted policy of certain municipal authorities will not be allowed to interfere with the progress of a movement destined to become of national importance.

The sale of electricity in Great Britain is now over one hundred million Board of Trade units per annum, or three times what it was four years previously. The capital expended in electric-supply undertakings already exceeds sixteen million pounds sterling, and the capital outlay for electric traction is even greater; and at this moment the number of miles of electric tramways under construction in Great Britain is fully equal to the miles of route already in operation. Last year eighty-nine provisional orders for electric lighting were granted. Electric Railway and Tramway Bills and Tramway Provisional Orders numbering forty-six received the Royal Assent; also applications for twenty-one light railways to be worked by electricity were received.

These facts point to great additions to our central stations; but it is neither for lighting nor for tramways that the real bulk of the energy will in the approaching future be required, but rather for manufacturing purposes. When electric energy can be generated and distributed at such a cost as to displace the use of the steam-power now employed in manufacturing works, the inauguration of a new era of centralisation in the supply of power will have commenced, the importance of which cannot be over-estimated. The average total cost of a unit of electricity generated by electric-supply undertakings in this country for 1898 was $2 \cdot 81d$., of which the expenses of generation amounted to $1 \cdot 79d$. With improved load-factors this figure would be less; but those who know the actual cost of steam-power generated on manufacturers' premises will appreciate how much this figure must be lowered, if the manufacturers are to be induced to take electric energy in bulk from outside companies. It is known that several companies will, under certain conditions, supply electric energy for power purposes at $1d$. per unit, this being possible because of the higher price paid for lighting current; but even this figure is too high for manufacturers who would require large currents. In Appendix II (page 76) the author has tabulated the approximate cost of power under different circumstances;

and from these figures it becomes clear that, unless the price is reduced to something like $\frac{3}{4}d.$ per unit, only the smaller manufacturers will benefit by the wholesale adoption of current supplied from central power-stations.

Where then is this cheap supply of electric energy to come from? In this country we have not the Niagara Falls with their 7,000,000 H.P. to draw upon, nor even the 600,000 H.P. of waterfalls said to be available in Switzerland; and it is certain that we must rely on the coal-supply as the only cheap source of power available in really large quantity. It is the object of the present Paper to enquire into the question of the use of power-gas and large gas-engines as a factor in the solution of the cheap-power problem.

The central stations which have so far adopted power-gas and gas-engines in this country are comparatively few and small. Of a total of seven stations the largest has an aggregate of 650 H.P. and the largest unit in use is 200 H.P. The reason for this state of things may be easily summed up. In the first place, until recently no gas-producer was commercially available which could make a reliable gas sufficiently cheaply or from any but expensive fuel, such as anthracite or coke; and secondly, no gas-engines of large size had been in use for a sufficient period of time to satisfy electrical engineers as to their suitability for working under station conditions. These reasons exist no longer, for there is in the Mond Producer the means of converting cheap forms of bituminous coal, or slack, into a clean gaseous fuel, suitable in every way for use in gas-engines, and at the same time of recovering the ammonia of the coal as a valuable by-product. The net result is that the fuel cost per unit of electricity generated—including all cost of labour, repairs, &c., at the gas-producer and recovery plant—is less than one-twentieth of a penny per unit at the switchboard. This figure represents the cost under actual conditions of continuous running at the works of Messrs. Brunner, Mond and Co., at Winnington, near Northwich, without allowing full credit for the sulphate recovered (see Appendix X (page 95)).

Secondly, gas-engines of 500 H.P. are already numerous, and one of 650 H.P. has been at work over a year, while others of 1,000

and 1,500 H.P. are building. On the Continent and in America the author has been specially studying the question of large gas-engines, and has had the opportunity of seeing the easy, comfortable way in which the 650-H.P. Westinghouse engine does its work.   Mr. George Westinghouse informed him that the Westinghouse Machine Co. had sufficient experience to make them feel quite confident of their ability to build 2,000 and even 3,000 H.P. engines, and work them with perfect success.

The special features of gas-engine practice, which have enabled gas-engines to be made of powers far beyond those formerly thought possible, may be briefly stated.   The most important is the improvement in the design of the cylinder-liner, the piston, and the valves, whereby they may all be efficiently water-cooled ; and probably a time will soon come when no engine of more than 17 inches diameter will be constructed without a water-cooled piston and a high degree of compression.   The better shape given to the clearance space, the arrangement of the valves in this space, the introduction of induced and positive systems of scavenging, and the better understanding of the causes of pre-ignition, have all aided in the forward progress of the gas-engine.   A noticeable strengthening of all working parts has also taken place.   Thus the Westinghouse practice is to make the crank-shaft half the diameter of the piston, and in larger sizes even more ; for example, with a 34-inch piston the crank-shaft is made 19 inches diameter.   Improvements in the breech-end castings, better arrangements for the contraction and expansion of the metal, improved means of ignition, and other items too numerous to mention, all help in a step-by-step progress towards gas-engines of great power.

In Appendix III (page 77) particulars of some large gas-engines are given. Appendix IV (page 78) contains the data, and Appendix V (page 81) the results of a trial of a 400-H.P. Crossley gas-engine, Plate 1, carried out by the author.   It will be seen that the normal-load trial of this engine gave a consumption of 60 cubic feet of Mond gas per hour per I.H.P., equivalent to a thermal efficiency of 26·2 per cent.   The gas was measured by a large station wet-meter of 50,000 cubic feet per hour capacity, erected specially for the experiments,

and in Appendix XI (page 96) the author has enumerated the precautions taken to ensure great accuracy in all the measurements of quantities involved in this trial, and in the other experiments recorded in the Paper. Indicator diagrams of the Crossley engine with their isothermal and adiabatic curves, together with the equations to the actual expansion and compression curves, are given in Fig. 1 (page 46). Other information relating to the valve motion, the "bottom loop" indicator diagrams, and the fluid resistance, is contained in Figs. 2, 3 and 4 (pages 47 to 49). The curves (page 49) are important as showing how large the fluid resistance may become in a big engine, especially if the governor is cutting out explosions so that the suction-stroke draws in air only. The length, size, and arrangement of the various pipes have considerable effect on the bottom-loop diagrams (page 48), and these matters are worth careful study in each individual case.

It was anticipated that the 400-H.P. Crossley engine would give fully 30 per cent. thermal efficiency; but the makers have kept down the degree of compression to so low a figure that the average effective pressure is only a little above 60 lbs. per square inch, and the thermal efficiency only 26·2 per cent. Although this engine has to run at full load day and night, this extreme measure of precaution would be quite unnecessary, if the pistons were water-cooled. However it is the first engine of its size Messrs. Crossley Brothers have made, and they are to be congratulated on having turned out a workmanlike and successful engine. The 500-H.P. " Premier " engine of the tandem positive scavenger type, Plates 2 and 3, when tested at the maker's works at Sandiacre, near Nottingham, with gas from a small Mond plant, gave 103 lbs. per square inch mean effective pressure in the motor cylinders. The results of the trials made by the author after this engine had been erected at Winnington are given in Appendix IV (pages 79–80) and Appendix V (pages 84–86). From the tabulated figures it will be seen that the highest thermal efficiency ever reached with producer-gas has been obtained with this engine, which will indicate 650 H.P. when running at the moderate speed of 128 revolutions per minute, and is the largest gas-engine in this country. Plans and elevations of the Crossley and " Premier " engines

FIG. 1.   400.-*H.P. Gas-Engine (Crossley).   Indicator Diagrams.*

The above indicator diagrams represent the average of all diagrams taken during the first six hours of the Official Trial, 10 April 1900.

FIG. 2.

400-H.P. Gas-Engine (Crossley). Diagram of Valve Motion.

Fig. 3.   400-*H.P. Gas-Engine (Crossley)*.
" *Bottom Loop* " *Indicator Diagrams*.
Spring 32 *lbs. to* 1 *inch*.

" A " Cylinder.   " B " Cylinder.
150 Revs. per minute.   Firing Cycle.

150 Revs. per minute.   Taking Air only.

94 Revs. per minute.   Firing Cycle.

94 Revs. per minute.   Taking Air only.

FIG. 4.   400-*H.P. Gas-Engine (Crossley) using Mond Gas.*

Curves showing Horse-Power lost in Fluid Resistance at different speeds.

I. Horse-Power lost when cylinder is run idle, taking in and discharging air only.

II. Horse-Power lost in Fluid Resistance when exploding at every cycle.

III. Percentage of return stroke where compression curve crosses the atmospheric line, for ordinary working cycle.

NOTE.—All three curves are obtained from " bottom loop " diagrams taken with a light spring.

installed in the power-house at Winnington, and used by Messrs. Brunner, Mond and Co. for their electrolytic plant, are given in Plates 1, 2 and 3, and Fig. 16 (page 50).

Though Mond gas is a most perfect fuel for gas-engines, there is another ideal fuel which, unfortunately, is not found in this country. The use of natural gas in the Pennsylvania and other districts of America has given a stimulus to the employment of gas-engines in the United States; but in a comparatively few years' time the present sources of supply of this gas will be practically exhausted. Appendix

F

VIII (page 91) gives the figures of a brake trial of a Westinghouse gas-engine using natural gas, abstracted for the author from the

FIG. 16.
150-H.P. Gas-Engine
(Crossley).
ELEVATION.

PLAN.

0   5 Feet

books of the Westinghouse Machine Co., when he had the pleasure of looking over their carefully kept records. These figures show the excellent economy of over 24 per cent. thermal efficiency, calculated on the B.H.P. and in a comparatively small engine. The system of governing, by controlling the quantity of gaseous mixture of constant quality, has been well worked out in Westinghouse engines, but is really applicable to a rich gas only. It was stated that in the large engines a consumption of 9 cubic feet of natural gas per B.H.P. hour had been reached, and that there were hopes of lowering the record to 8 cubic feet with the 1,500 H.P. engines.

America, France, Germany, Belgium, and lastly England, are now turning out large gas-engines, and the author has information to show that the orders for large gas-engines exceeding 500 H.P. amount collectively to over one hundred engines. With such results before them, the time has certainly arrived for a careful study of the advantages to be gained by combining a Mond producer-plant with gas-engines. The subject may be considered under the following headings :—

The possibility of using cheap fuel, and of recovering its
ammonia.

The greater economy of gas-engines as compared with steam-
engines.

The simplicity and reliability of gas-engines.

The superiority of gas-producers over steam-boilers.

Costs.

Mond Gas.—The possibility of using cheap fuel and of
recovering its ammonia has been the subject of Dr. Mond's
experimental work on gas-producers, which was started in 1879, and
has been carried out on a large scale for a number of years at
Winnington, Cheshire (Plates 4 and 5).   This work resulted in the
solution of the difficult problem of converting the cheap forms of fuel
into a good gas of uniform quality, in such a way that the ammonia
existing in the fuel is not destroyed, but recovered as a by-product.
This process will be briefly described with the help of the diagram,
Fig. 21 (page 52).   Common bituminous slack, brought by railway
wagons into the works, is mechanically handled by elevators and
creepers, and deposited in hoppers above the producers.   From these
it is fed in charges of 8 to 10 cwts. at a time into the producer " bell,"
where the first heating of the slack takes place, and the products of
distillation pass downwards into the hot zone of fuel, before joining
the bulk of the gas leaving the producer.   The hot zone destroys
the tar and converts it into a fixed gas, and also prepares the slack
for its descent into the body of the producer, where it is acted upon
by an air-blast, which has been saturated with steam at 85° C.
(185° F.), and superheated before coming into contact with the fuel.
Unlike what is done in other producers, the quantity of steam
introduced into the blast is relatively large, and amounts to $2\frac{1}{2}$ tons
for every ton of fuel gasified.   This large quantity of steam keeps
down the working temperature of the producer within such
limits, as to prevent the formation of clinkers or the destruction
of the ammonia, yet permits the fuel to be so thoroughly
burned that good ashes are obtained.   Half a ton of steam is
decomposed in the producer for every ton of fuel burnt, yielding

thereby free hydrogen to the extent of 29 per cent. by volume
in the final gas. The hot gas and undecomposed steam leaving the
producer pass first through a tubular regenerator in the opposite
direction to the incoming blast. An exchange of heat takes place,
and the blast is still further heated by passing down the annular
space between the two shells of the producer on its way to the
fire-grate. Then the hot products from the producer are further
passed through a " washer," which is a large rectangular wrought-
iron chamber with side lutes; and here they meet a water-spray
thrown up by revolving dashers, which have blades skimming up

FIG. 21. *Diagram illustrating method of working Mond Plant.*

the surface of the water contained in the washer. The intimate
contact thus secured causes the steam and gas to be cooled down to
about 90° C. (194° F.) ; and by the formation of more steam, tending
to saturate the gas with water-vapour at this temperature, the
bulk of the sensible heat is converted into latent. Then passing
upwards through a lead-lined tower, filled with tiles to present a
large surface, the producer-gas meets a downward flow of acid liquor,
circulated by pumps, containing sulphate of ammonia with about
4 per cent. excess of free sulphuric acid. Combination of the
ammonia of the gas with the free acid takes place, giving still more

sulphate of ammonia, so that to make the process continuous some sulphate liquor is constantly withdrawn from circulation and evaporated to yield solid sulphate of ammonia, and some free acid is constantly added to the liquor circulating through the tower. The gas, being now freed from its ammonia, is conducted into a gas-cooling tower, where it meets a downward flow of cold water, thus further cooling and cleaning it before it passes to the various furnaces and gas-engines in which it is used. The cooling of the gas with its burden of steam results in the condensation of the steam, and in raising the temperature of the cooling water, so that the latter leaves the bottom of the tower as *hot* water, which is utilised in a third tower called the "air-heating tower," through which the air-blast from the blower is directed. Here the contact of hot water and cold air gives cold water and hot air, saturated with water vapour at 73° C. (163° F.). By this method of utilising the heat of the gas from the producer, nearly 1 ton of steam is added to the producer-blast for every ton of fuel gasified; and this cyclical exchange of heat is always going on; and forms one of the distinctive features in the economy of the process. The hot water from the gas-cooling tower is circulated through the air-heating tower, and being thereby cooled is again pumped up to the top of the gas-cooling tower. Both towers are filled with tiles to give large surfaces of contact, and the circulating water acts as the heat-carrying agent between the hot gas and the cold air. The charging of the fresh fuel into the top of the producer and the withdrawing of ashes from the bottom in no way interfere with the continuous steady work of the producer. Also the large volume of steam employed acts as a most perfect regulator in keeping the quality of the gas uniform. Each Mond producer of the ordinary size used at Winnington is capable of gasifying 20 to 24 tons of slack per day of twenty-four hours, and the volume of gas furnished from 1 ton of fuel fed into the producer varies from 140,000 to 160,000 cubic feet, according to the quality of the slack, and is sufficient to develop 2,000 I.H.P. hours when utilised in a gas-engine. The value of the sulphate of ammonia recovered from 1 ton of fuel is, at present prices, 8s. naked at the works.

In Appendix I, Tables 1 and 2 (pages 73 to 75), are given the most recent figures relating to the Mond producers as worked at Winnington, where the gas is used for a great variety of purposes. These figures show the analysis of the slack used, the gas made, and the ashes drawn from the producer; also weights, specific gravity, yield of gas, calorific values, air required for combustion,

Fig. 22.

Mond 6 Producer Plant to supply Gas for 10,000-H.P. of Gas-Engines.
A = Air Main.   G = Gas Main.

specific heats, and other figures. In fact, all such information as will enable an engineer to make any calculations he may require in adopting the plant for central-station work. Appendix XII (pages 98 to 100) is added, as containing necessary figures for dealing with all calculations relating to volumes of producer-gas, and which are now published for the first time. The general

FIG. 23. Recently designed 6 Producer Plant with Sulphate Plant.

diagram, showing the method of working the Mond plant, given in Fig. 21 (page 52) is not to scale. Three views of a plant to supply gas for 10,000 H.P. of gas-engines are shown in Fig. 22 (page 54); and a more recently designed plant for six producers, with sulphate plant, is shown in ground plan, Fig. 23 (page 55).

Greater Economy of Gas-Engines as compared with Steam-Engines.— Dealing now with the question of fuel economy, Fig. 24 shows in a striking manner how much more economical gas-engines and Mond producers are than steam-engines and steam-boilers. The economy is three-fold, because (a) the fuel for generating Mond gas is cheaper than the fuel used at central stations for producing steam. (b) For a given expenditure of heat, the calorific value of the Mond gas from the producer is greater than the calorific value of the steam from the boiler; and (c) the gas-engine utilises the heat received much more efficiently than does the steam-engine. Referring to the diagram it will be seen that the actual results obtained at Winnington are not only far superior to the actual results for any central station using steam-driven plant, but are a long way better than the ideal figures for the latter. Some notes on the diagram are added in Appendix X (page 95).

In 1898, for eighty-three electric-supply undertakings in Great Britain, the cost of fuel was 47 per cent. of the generating cost, and 30 per cent. of the total cost per unit. As central stations become larger and get better load-factors, the question of fuel economy becomes of increasing relative importance, as it forms a larger proportion of the total costs.

Simplicity and Reliability of Gas-Engines.—With regard to the reliability of gas engines, the author is able to give some remarkable figures relating to a gas-engine (called by Messrs. Crossley Brothers a 60-N.H.P. gas-engine), direct-coupled to a Siemens dynamo, in use at the works of Messrs. Brunner, Mond and Co., where it is employed along with steam-engines generating current for an electrolytic process. This power plant has been under the author's supervision since it started in 1897, and all the gas used by the

Fig. 24.   *Heat Consumed in Producing One Kilowatt-hour.*
(See Appendix X, page 95.)

I. Very good actual results for a Central Electric Light Station.

II. Ideal figures for a Central Electric Light Station, based on Professor A. B. W. Kennedy's estimate.

III. Ideal figures for Continuous Running, based! on Professor W. C. Unwin's estimate.

IV. Actual results for Continuous Running, at Winnington, Cheshire, 1898.

Lb. Degree Centigrade Heat Units

47,400
44,000
40,000
36,000
32,000
28,000   27,970
24,000   25,888
20,000   23,913
16,000   18,518   17,236
12,000   11,520   9,675
8,000
4,000   1,904   1,904   1,904   1,904
—0

Cost in Pence

0·2   0·048
0·4   0·385   0·194
0·6
0·8   0·7
1·0

I   II   III   IV

Steam   Steam   Steam   Large Gas-Engine
Engines.   Engines.   Engines.   using Mond Gas.
(Actual)   (Ideal)   (Ideal)   (Actual)

This extension shows the actual Fuel Cost for the 83 principal Electric Supply Undertakings in Great Britain for the year 1898. 0·778d. per unit sold, probably about 0·65d. per unit generated.

Calorific Value of Fuel consumed (at 7,900 lb. C.° units per lb.).

Heat Units in Steam or Gas reaching Engine.

Heat Equivalent of one Kilowatt-hour at Switchboard.

Cost for Fuel used.

NOTE.—Coal for Steam-raising is taken at 12s. per ton.
Slack for Mond Producers is taken at 5s. per ton.
Calorific Value of (dry) slack is 6,786 lb. C.° units per lb.

engine has been measured through a large wet-meter, so that the
exact quantity used during two years' work is known.   The
plant runs day and night, and hourly readings of output and all
other quantities involved are kept throughout the year.   The
figures for the two years are given separately in Appendix VII
(page 90), as they show the difference in results when working
on the " hit and miss " principle of governing, with some missed
explosions, and when exploding every possible time with a somewhat
weaker mixture, so as to keep the output about the same in both
cases.   The engine ran, with an average output for the two years of
88·8 E.H.P., for 16,930·9 hours out of a possible 17,520 hours, or
96·6 per cent. of the whole time. .The running included a period
of 138 days and nights, during which the engine ran continuously
without a single stop.   The average I.H.P. was 114·7, and the
average thermal efficiency for the whole of the two years was 25·1
per cent., calculated on the I.H.P. and the calorific value of the gas
used.   The official test of this engine is also given in Appendix VI
(page 87), but engineers will appreciate more the results of steady
working over long periods.   The cost of repairs has been exceptionally
low, and not a single cam or roller shows signs of heavy wear.   The
only parts renewed in two and a half years are one set of piston
rings, some valve springs, and small brass ignition-valves.   One of
the main bearings had to be repaired, but this was due to neglect in
looking after the lubrication.   The gas, air, and exhaust valves look
as good as ever, and the engine is steadily improving its record.
The consumption of coal fed into the producer averages 1·05 lb. of
slack per I.H.P. hour, and the consumption of oil for the last year
works out at 0·0235d. per unit.   The absence of all glands and
packing is a great point in favour of gas as against steam-engines.
A few words should be added regarding the dynamo, which has run
absolutely without any repairs at all.   The remains of the original
brushes are still in use, and the commutator has never required
turning up ; it has not even been touched with a sheet of emery,
although it has generated about one and a half million units up to
October 1900.   The work of this gas-engine is undoubtedly
the best on record, and is only possible because Mond gas is of

uniform quality, and free from grit and impurity. It is hoped, however, that such results will soon be a matter of common experience. Equally good results are expected from the two large gas-engines already mentioned, which Messrs. Brunner, Mond and Co. have added to their electrolytic plant to replace modern, quick-revolution steam-engines, and for purposes of extension.

In considering the application of gas-engines to central-station work, it must be borne in mind that the large central station of the future will employ three-phase alternating currents ; and the important question arises, are gas-engines, coupled to alternators, suitable for running in parallel ? In answer to this the author has seen, at the works of the Solvay Process Co., Syracuse, U.S.A., the first gas-alternator which successfully accomplished such parallel running. It is a 150-B.H.P. three-cylinder vertical enclosed Westinghouse gas-engine. The cylinders are 13 inches diameter, the stroke 14 inches, and the speed 300 revolutions per minute. The alternator is direct-coupled, and of 75 kilowatt capacity, generating two-phase current of 60 cycles per second at 400 volts, and running in parallel with Westinghouse steam-alternators in the same station. No difficulty has been found in running this engine in parallel with the others.

The three-cylinder Westinghouse vertical engines are now being made up to 1,500 B.H.P. Such an engine, which the author saw under construction, had cylinders 34 inches diameter and 5 feet stroke, and was intended to run at 100 revolutions per minute. This class is well suited for direct-coupling to alternators, and the illustration, Plate 6, shows a proposed station of 30,000 H.P. of gas-engines, and gives a good idea of the appearance of the 1,500-H.P. engine. With the more general introduction of such engines, there is little doubt that the difficulties of parallel running of gas-alternators will be completely overcome, even if M. M. Leblanc's invention of the " amortisseur " has not already solved the problem. With an additional outlay of capital, the question of the alternators running in parallel may be completely removed, and an extremely elastic method of working adopted. It would consist of working all the gas dynamos on direct current, and using this

Fig. 26. 400-H.P. Gas-Engine (Crossley) working with Mond Gas.
Indicator Diagrams, Inertia Forces, Resultant Pressures, and Turning Moments.

Indicator Diagram . . . . Lbs. per sq. inch.
Inertia Forces due to Reciprocating Parts — — — Calculated to lbs. per sq. inch of piston area.
Indicator Diagram corrected for Inertia ——— Resultant lbs. per sq. inch
Turning Moment at Crank Shaft +++++ Foot lbs. per sq. inch of piston area.

"A" Cylinder.

"B" Cylinder.

one revolution

one revolution

Pressure in lbs. per sq. inch.

Pressure in lbs. per sq. inch.

The diagrams are drawn with the stroke as base; the dots on the corrected diagram show equal crank angles.

FIG. 27. 400-H.P. Gas-Engine (Crossley).

Diagrams showing the Combined Turning-Moments on the crank shaft for "A" and "B" Cylinders, and the resulting Speed Variation during one complete cycle.

These curves are drawn on a base of equal angles of crank motion.

NOTE.—The effect of friction is neglected in these diagrams.

current to drive motor-alternators. The latter would be situated in a separate building along with all the service switchboards and appliances, and would form an ideal installation as regards ease of control, freedom from noise and heat, and adaptability to supply electric energy in more than one form, so as to meet various requirements.

Other large gas-engines in Belgium and Germany are referred to in Appendices XIII and XIV (pages 101–117).

Steadiness of running is a matter of great importance in a gas-engine, and the author has made a number of experiments on the 400-H.P. Crossley engine at Winnington, the results of which are given in Appendix V, Tables 2, 3, and 4 (pages 82 to 84). Fig. 26 (page 60) shows the indicator-card plotted progressively on a four-stroke base, equal to a complete cycle. The forces due to the inertia of the moving parts, the diagram as corrected for these, and the calculated turning-moment on the shaft, are also shown. In Fig. 27 (page 61) the combined turning-moment for " A " and " B " cylinders is plotted on a base of angular motion of the crank, and from this the cyclical variation of speed has been calculated and plotted to a magnified scale. Crossley's arrangement of the two cylinders, so that two explosions take place in one revolution and none in the next revolution, gives a much less steady turning-moment than the arrangements adopted by Westinghouse, the Premier Co., or Körting, respectively ; yet the speed variation is remarkably small. In Fig. 27, where the variation is shown to a magnified scale, it appears serious ; but that in reality it is extremely small is best shown by integrating the speed-curve and comparing the running with another imaginary fly-wheel loose on the same shaft, and moving at a uniform speed equal to the actual mean-speed of the engine fly-wheel. Then the relative positions of the two wheels are found not to differ by a half-degree at any point in the two revolutions constituting a complete cycle. Similar tables and figures are given for the 500-H.P. " Premier " engine, Appendix V, Tables 5 and 6 (pages 84–86), and Figs. 30–32 (pages 65–67). In comparing the speed-variation curves of the two

FIG. 28.   400-*H.P. Gas-Engine (Crossley) using Mond Gas.*
Curves showing I.H.P. developed in each Cylinder, and quantity of Gas used
per stroke, when working with various proportions of Gas
and running at 120 revolutions per minute.

Cubic Feet of Mond Gas (reduced to 0°C and 760 m.m.) used per stroke.

NOTES.—Explosion occurred at every cycle. The curves cover the whole range of explosibility of the gas. Weaker or stronger mixtures would not, under the conditions obtaining, explode with certainty. The speed of 120 revs. per min. was chosen for these experiments because the power developed with weak mixtures was not sufficient to overcome the engine friction at higher speeds. With very rich mixtures, ignition occurs at irregular points in the stroke, and the I.H.P. is consequently unsteady. A small increase of gas above 3·2 cubic feet per stroke will cause the charge to misfire and the output to drop suddenly. The marked difference between the I.H.P. for " A " and " B " cylinders, when consuming the same quantity of gas, is principally due to the degree of depression being higher in " B " cylinder. To get the extreme range of mixture, either the gas or air-supply had to be considerably throttled. Consequently the total volume of mixture per stroke is not constant, and the cubic feet of gas used per stroke is not an exact indication of the strength of the mixture.

engines, it is necessary to remember the different speeds at which
they run, and that the energy stored in a fly-wheel is proportional
to the square of the speed.

With the cyclical speed-variation brought within such narrow
limits that alternators can safely run in parallel, the ordinary
speed-variation, as controlled by the governor, can be readily dealt

FIG. 29.   400-*H.P. Gas-Engine (Crossley) using Mond Gas.*
Curves showing the Thermal Efficiency for varying quantities of Gas per stroke.

Cubic Feet of Mond Gas (reduced to 0°C and 760 m.m.) used per stroke.

with.   In this connection, it is important to bear in mind the wide
range over which Mond gas will form mixtures with air of various
explosive intensity.   Fig. 28 (page 63) shows how the output of the
engine can be controlled by controlling the quantity of gas per stroke,
instead of by a " hit and miss " system.   The thermal efficiency curve
of Fig. 29 is seen to be sufficiently flat over a wide enough range to
admit this kind of governing, without much loss of efficiency.   The
400 H.P. Crossley engine referred to is fitted with a graduated or
stepped gas-die, upon which the gas-lever and knife-edge strike.
The governor determines the position of this die, and consequently
also the amount of gas admitted.   This principle however is
not new.

Fig. 30.   500-H.P. (600-I.H.P.) Gas-Engine (Premier).

Average of all diagrams taken during the trial on 7 December 1900.   Diameter of cylinders, $28\frac{1}{2}$ inches.   Stroke, 30 inches.   Speed, 128 revolutions per minute. Working with Mond Gas.

The best average card from the 400-H.P. Gas-Engine (Crossley) is shown dotted, for comparison of pressures throughout the stroke.   Crossley Engine.— Diameter of cylinders, 26 inches.   Stroke, 36 inches.   Speed, 150 revolutions per minute.

The clearance volume of the back cylinder is $27 \cdot 0$ per cent. of the working stroke, or $21 \cdot 26$ per cent. of the total volume.   The equation to the expansion curve is for the portion between $0 \cdot 1$ and $0 \cdot 9$ of stroke.

G

FIG. 31.   500-H.P. Gas-Engine (Premier), working with Mond Gas.

The diagrams are drawn with the stroke as base ; the dots on the combined diagram show equal crank angles.

FIG. 32. 500-H.P. Gas-Engine (Premier).

Diagram showing the Combined Turning-Moments on the crank shaft for both Cylinders, and the resulting Speed Variation, during one complete cycle.

These curves are drawn on a base of equal angles of crank motion.

NOTE.—The conditions here assumed are not those of the actual test, because (a) the ordinary working speed of 125 revs. per min. has been taken ; and (b) for purposes of comparison the Moment of Inertia of all rotating parts has been taken the same as for the 400-H.P. Gas-Engine (Crossley).

Appendix V, Table 3 (page 83) gives the ordinary speed-variation under actual working conditions, and with different systems of governing. These results have been recorded by means of a drum, driven direct by the engine-shaft, and carrying smoked paper upon which a standard electrical tuning-fork draws the vibration curves of equal time intervals. The apparatus was improved in some details by Mr. H. B. Ransome, and called by him a "Cyclometer," and is shown in Plate 7.

With the ordinary "hit and miss" method of governing, the speed varies $0 \cdot 976$ per cent. on either side of the mean, but if the engine is allowed to explode every possible time (and this is the usual method of working at Winnington), the running is so steady that the variation is only $0 \cdot 0937$ per cent. above and below the average. It was intended to use the cyclometer to measure the cyclical speed-variation, but the author found this to be so small that the possible error of measuring the length of a fixed number of vibrations, during fractions of a revolution, was about of the same order as the differences to be determined, and in consequence he calculated the variation throughout the stroke as given in Fig. 26 (page 60). This method was long and tedious, but is undoubtedly more accurate, although it neglects the effect of engine friction.

Gas-producers compared with Steam-Boilers.—Turning now to the subject of gas-producers as compared with steam-boilers, it will at once be obvious that gas under a slight pressure is much easier to handle than high-pressure steam, and when steam-mains cease to be necessary, a cause of danger and trouble is removed; also the losses due to condensation disappear at the same time. It is perhaps of still greater importance that the working, as between producers and gas-engines, can be controlled automatically in the most perfect manner, so that the gas supplied is always equal to the gas consumed. At Winnington, where 1,000,000 cubic feet of gas are consumed per hour, and demands for gas are by no means regular, there is no gas-holder or storage of any kind. A Mond producer will respond at once to a sudden increase in demand for gas, whereas a steam-boiler takes time to rise

to the increased output, and the boiler foreman has his anxious half-hour as the peak of the load-curve arrives for his station. The speed of the air-blower furnishing the blast to the producers can be controlled by the pressure of gas in the supply mains, and any fluctuation is automatically balanced so as to keep the supply pressure constant. The limits within which a Mond producer will make good gas are surprising, and a producer can be shut down and left with fire in it for over a week, and still be quite ready to start again at short notice. With producers the stand-by losses are reduced to a minimum, and thus another serious waste is avoided when compared with steam practice. It should be made quite clear however that when the Mond plant is arranged for the recovery of ammonia, some steam, as shown in the Appendix X (page 95), is required in order to provide the balance of water-vapour necessary to saturate the producer-blast. This steam can be raised by utilising the heat of the exhaust gases leaving the gas-engines, and a large plant has been designed, and will be erected, in which all the extra steam required will be raised in this manner. But where it is not convenient to extract the heat from the exhaust gases, some steam-boilers become necessary. Such boilers could be gas-fired, and the control rendered automatic. If the recovery of ammonia is not attempted, less steam is required in the blast, and arrangements can be made to do without steam-boilers. In a large station however the sacrifice of the ammonia represents about 4s. 6d. per ton of slack. Also, as the recovery plant is so simple, station engineers should welcome this source of economy with the same readiness with which they will appreciate the use of cheap bituminous fuel.

In the Mond gas plant is found a perfect system of producing cheap power-gas, which, when combined with the use of gas-engines, forms the cheapest, the most scientific, and the most economical method of dealing with fuel. Several companies have grasped this fact and adopted the system, and soon there will be some 2,000 to 4,000-H.P. plants at work. It is significant that the Northwich Electric Supply Co. preferred to buy Mond gas, and pay as much as 2d. per 1,000 cubic feet for it delivered under pressure on their premises, rather than use the water-power available in the district.

Cost.—The question of cost is the crucial test, when once the absolute reliability of the system is assured ; and its recommendation must be based on the commercial results to be obtained. The cost can be fairly closely estimated on the basis of the Mond plant at Winnington, where 150 to 230 tons of fuel per day are gasified. All

FIG. 35.   *Diagram of 250-H.P. Mond Gas Plant.*


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0     5     10     15     20     25     30 Feet
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that can be attempted in the present Paper is to give a general idea of the cost of working a central station under a fixed set of conditions; and in Appendix IX (pages 93 and 94) have been purposely omitted all charges on capital outlay for land, buildings, gas-dynamos, &c., being capable of estimation from data, which would be somewhat modified to suit each individual case. The station has been chosen at 20,000 E.H.P., and the load factor assumed at 100 per cent., 50 per cent., and $33\frac{1}{3}$ per cent. successively. The first case applies only to an electrolytic plant, but the other two may well represent a future central station supplying energy in bulk. The cost of fuel, oil, labour, repairs, and maintenance, ranges from $0\cdot082d.$ to $0\cdot241d.$ per unit sold, according to load factor and price of coal.

As regards capital outlay, the combination of Mond producers, recovery plant, gas-engines and dynamos, compares favourably with the best class of steam-driven plant, when the boiler-house, chimney,

slack-handling appliances, foundations and erection, are included in the cost of steam-dynamos, boilers, condensers, and auxiliary machinery. From actual experience with 400-H.P. units, the cost of gas-engines, dynamos, fly-wheels, &c., with foundations and erection, is £12·42 per E.H.P. capacity, or £16·64 per kilowatt. Adding to this the cost of the complete producer and recovery plant, with its buildings, &c., at £4·62 per kilowatt (including 20 per cent. reserve) a total is obtained of £21·26 per kilowatt. With large units this cost would be materially reduced, and £15 or £16 per kilowatt would probably cover the cost with a 20,000-E.H.P. plant.

To pass for one moment from large to small schemes, it may be of interest to state that Mond producer-plants have been designed to supply gas for small powers down to 250 H.P. of gas-engines. These plants are simple in construction, as shown in Fig. 35 (page 70), and work under an important plan of Dr. Mond's, whereby a portion of the exhaust gases from the gas-engine is introduced into the producer blast, thus keeping down the temperature of the producer without the use of extra steam. In these small plants no recovery of ammonia is attempted, and the apparatus is intended only to supply the requirements of isolated places where a good power-gas or heating-gas is necessary.

In conclusion, the author desires to express his thanks to Dr. Ludwig Mond, for his kind permission to place before the Institution much of the information contained in this Paper. Most of the experiments were carried out for Dr. Mond at his expense and that of the great firm of chemical manufacturers with which he is associated, and through Dr. Mond's generosity it has been possible for the author to embody the more important results of this work in the present Paper. It should be understood however that the preparation of the Paper, with all the calculations and diagrams, has been done in the author's own time, on his own initiative, and is therefore entirely independent of any official duties. His thanks are also due to M. Adolphe Greiner, director of the John Cockerill Society, for the particulars of the tests made at Seraing; and to Professor F. W. Burstall, the Reporter to the Gas-Engine Research Committee of this Institution, for the loan of some carefully calibrated apparatus, which has been useful for purposes of comparison.

The Paper is illustrated by 9 Plates and 22 Figs. in the letterpress, and is accompanied by XIV Appendices :—

LIST OF APPENDICES.

APPENDIX I.

TABLE 1.

Typical Figures for the Mond Producer and Recovery Plant.

The figures contained in Table 1 and 2 differ somewhat from those given in the author's Paper * read before the Institution of Civil Engineers, because of the inferior quality of fuel now employed. When the poorer class of fuel used is taken into consideration, the results now stated are superior to those previously given.

Average Analysis of Fuel (by weight) :—

	Slack as received. Per cent.	Calculated on dry slack. Per cent.
Moisture at 100° C. (212° F.)	8·60	nil.
Volatile matter (excluding carbon) . . .	18·29	20·01
Total carbon	62·69	68·59
Ash	10·42	11·40
	100·00	100·00

Analysis of Ashes leaving the Producer :—   Per cent.

Ash on dried sample, by weight	87·0
Carbon	13·0

	Per cent.
Total carbon lost in ashes, &c., calculated on the fuel used . .	5·31
Carbon available for conversion into gas	57·38

Calorific Value of Fuel (tested on dry sample) :—

Determined by combustion in compressed oxygen, in a Bomb Calorimeter, kilogram-calories	6786
Kilogram-calories per ton of dry fuel	6,894,576

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* Proceedings, Institution of Civil Engineers, 1896–97, vol. **cxxix**, page 190.

Typical Volumetric Analysis of Mond Gas (dry) :—

		Volume per cent.
Carbonic Oxide	(CO)	11·0
Hydrogen	(H)	29·0
Marsh Gas	(CH₄)	2·0
Carbonic Acid	(CO₂)	16·0
Nitrogen	(N)	42·0
		100·0

Weight of 1 cubic mètre (35·32 cubic feet) of
 dry gas at 0° C. .   .   .   .   . 1,020 grammes (2·24 lbs.)
Weight of 1,000 cubic feet of dry gas at 0° C. . 63·66 lbs.
Specific gravity of Mond gas (air = 1)   .   . 0·7882

Each kilogramme (2·2 lbs.) *of* (*moist*) *fuel gasified yields* :—
            3·690 cubic mètres (130·33 cubic feet) of dry gas at 0° C.
            3·959 „   „   (139·79 cubic feet) gas saturated at 15° C.
                    (59° F.)

One ton of (*moist*) *fuel gasified yields* :—
   132,414 cubic feet (or 3,749·0 cubic mètres) of dry gas at 0° C.
   142,069 „   „ (or 4,022·3 „   „) gas saturated at 15° C. (59° F.)

Calorific Value of Mond Gas (products cooled to 18° C.) (64° F.) :—

	Gas dry. at 0° C.	Gas saturated. at 15° C.
One cubic mètre (m^3),		
in kilogramme-Centigrade units . .	1414·3	1317·8
One cubic foot,		
in lb.-degree Centigrade units . . .	88·26	82·25
in British thermal units	158·8	148·0
Calorific value of total gas made, in percentage		
on calorific value of total fuel gasified		. 84·1 per cent.

Combustion of Mond Gas and Air :—

One volume of gas requires for perfect combustion . .	1·15 vols. air.
Volume of mixture before combustion	2·15 vols. at 0° C.
Volume of products (cooled to 0° C.)	1·95 vols.
Contraction due to combustion	9·3 per cent.

   One cubic mètre (35·32 cubic feet) of gas, weighing 1·02 kilogrammes
(2·2 lbs.), requires for combustion 1·15 cubic mètres (40·62 cubic feet) of air,

weighing 1·487 kilogrammes (3·3 lbs.), and yields 1·95 cubic mètres (68·9 cubic feet) of products, weighing 2·507 kilogrammes (5·5 lbs.)

The gas generated by gasifying one kilogramme (2·2 lbs.) of moist slack requires for combustion 4·243 cubic mètres (149·86 cubic feet) of air, weighing 5·486 kilogrammes (12·1 lbs.)., and yields 7·195 cubic mètres (254·13 cubic feet) of products (at 0° C.), weighing 9·243 kilogrammes (20·3 lbs.).

If Mond gas is burnt with the theoretical quantity of air, the products, tested on the dry sample, should show 17·9 per cent. CO_2 by volume.

Specific heat of Mond gas at constant pressure .				.	.	.	.	.	0·3201
,,	,,	,,	,,	volume	.	.	.	.	0·2321
								Ratio =	1·379
Specific heat of products of combustion, at constant pressure							.	.	0·2622
,,	,,	,,	,,	,,	,,	volume	ˈ.	.	0·1922
								Ratio =	1·364

Theoretical temperature of combustion of Mond gas in air,

both being at 15° C. (59° F.) before combustion	.	1611° C. (2932° F.)
Temperature actually obtained without regeneration	.	1100° C. (2012° F.)

TABLE 2.

Quantity of Material entering the Mond Gas-Producer
per Kilogramme (2·2 lbs.) of Fuel Gasified.

								kg.	lbs.
Fuel	Dry slack.	.	.	.	.	.		0·9140	2·01
	Moisture .	.	.	.	.	.		0·0860	0·19
Steam	From air-heating tower	.	.	.				0·8396	1·85
	Extra steam added .	.	.	.				1·3338	2·93
Air	.	.	.	.	.	.	.	2·5265	5·56
						Total		5·6999	12·54
Steam decomposed in the producer .			.	.		.		0·5342	1·17
Mond Gas leaving the producer		.	.	.		.		3·7638	8·28
Ammonia recovered, approximately .			.	.		.		0·0100	0·02

APPENDIX II.

Cost of Energy.

Cost of One Electrical Horse-Power-Hour at the Switchboard.
(Under favourable conditions.)

Including fuel, labour, oil, stores, repairs, maintenance, and superintendence, but excluding interest, depreciation, rents, rates, and taxes. Coal taken at 10s. per ton.

	Cost of 1 E.H.P.-hr. *d.*
Steam-Engine and Dynamo Plant :—	
Electrolytic plant of 5,000 H.P., running night and day . .	0·29
Electric supply station, if with 50 per cent. load factor . .	0·51
Large manufacturing works possessing its own electric plant, and working factory hours with fairly steady load . .	0·46

Cost of One Brake-Horse-Power-Hour at the Driving Engine.

(Under favourable circumstances, and including the same items as the above.)

	Cost of 1 B.H.P.-hr. *d.*
Ordinary manufacturing works with fairly uniform load . .	0·68
Small ,, ,, ,, ,, . .	1·30
Ordinary ,, ,, ,, varying load . . .	0·96
Small ,, ,, ,, ,, . . .	1·80

NOTE.—The above figures have been arrived at after carefully tabulating various cost figures during a number of years. They are based partly on the author's own experience and partly on information obtained as the result of enquiry. The various costs are not comparable among themselves, unless the difference in the class of machinery used, conditions of working, &c., are fully allowed for. Each estimate must be regarded as an isolated statement.

APPENDIX III.

Particulars of some Large Gas-Engines.

Engine.	I.H.P.	Number of cylinders.	Diameter of cylinder. (inches)	Length of stroke. (inches)	Revolutions per minute.	Kind of Gas used.	Remarks.
Crosley engine, direct coupled to dynamo.	450	2	26	36	150	Mond	These engines run day and night at Messrs. Brunner, Mond and Co.'s works, supplying current to electrolytic plant.
"Premier" engine, direct coupled to dynamo.	650	2	28	30	150	Mond	Besides the engine working at Seraing, a large number of these engines are in course of construction.
"Simplex" engine built by the John Cockerill Society, direct coupled to blowing engine.	700	1	51	55	80	blast-furnace	Direct coupled to dynamo, at Hörde.
Oechelhaeuser, with two pistons in each cylinder.	600	2	18·9	31·5	135	"	Several engines of these sizes are building.
	1,000	1	25·6 / 36·8	50			
Westinghouse, direct coupled to dynamo.	650	3	25	30	130	natural	At work in Pittsburg, others building.
Koerting Bros., double-acting, direct coupled to dynamo.	1,500	3	34	60	100	"	Two building.
	500	1	21·6	31·6	110	producer	Gas and air pumped separately and supplied under pressure.
Crosley engine, direct attached to blowing cylinders.	600	2	30	36	135	blast-furnace	The blowing cylinders form the enlarged front portion of the motor cylinders, and are 63 inches diameter.

APPENDIX IV.

Particulars of 400-*H.P.* (*Crossley*) *and* 500-*H.P.* (*Premier*)
Gas-Engines working with Mond Gas.

400-*H.P. Engine and Dynamo.*—The engine, Plate 1, was made by Messrs.
Crossley Brothers, of Openshaw, Manchester, for Messrs. Brunner, Mond and Co.
It has two cylinders with the open ends facing one another, and the connecting-
rods working on a crank common to both. The dynamo, to which the engine
is direct coupled by means of a "cheese" coupling, was made by Messrs.
Mather and Platt, of Salford, Manchester, and has a capacity of 247·5
kilowatts, being constructed to deliver 2,250 ampères at 110 volts. It is an
8-pole machine separately excited.

Engine.—Diameter of cylinders　　.　　.　　.　　.　　.　　. 26·0 inches.
　　　,,　　　Length of stroke　　.　　.　　.　　.　　.　　.　　. 36·0　　,,
Speed. — Revolutions per minute　　.　　.　　.　　.　　.　　. 150

Weights and Inertia.—The total weight of the fly-wheel and
accessories, two crank-slabs, two balance weights, crank-pin,
equivalent rotating part for two connecting-rods, and engine shaft
and armature, is equal to　.　　.　　.　　.　　.　　.　　.　　. 87,638 lbs.
Moment of inertia for all rotating parts (units in lbs. and feet)　. 62,654
"M" for all rotating parts .　　.　　.　　.　　.　　.　　.　　. 343·5

Weight of Reciprocating Parts.—

One piston, cross-head pin, and equivalent reciprocating
　　　part for one connecting-rod　.　　.　　.　　.　　. 2,080 lbs.
Reciprocating weight per square inch of piston area　. 3·918 ,,
Length of connecting-rod　.　　.　　.　　.　　.　　. 6·707 ft.
Velocity of crank-pin at 150 revolutions per minute　. 23·57 ft. per second.

Acceleration of Reciprocating Parts.—
The following approximate formula has been used :—

$$A = \frac{dv}{dt} = \frac{d^2x}{dt^2} = -\, qr\left\{ \cos\, qt + \frac{r}{l}\cos\, 2qt \right\}$$

where q = angular velocity of crank in radians per second.
　　　v = linear velocity of crank-pin.
　　　x = displacement of piston from mid-stroke.
　　　　= time. A = acceleration of piston.

Crank angle, from horizontal.	Acceleration in feet per sec. per sec.	Force producing acceleration in lbs.	Force in lbs. per sq. inch of piston.
0°	453·2	29,270	55·14
15°	429·5	27,740	52·25
30°	362·1	23,390	44·06
45°	261·9	16,920	31·86
60°	143·8	9,287	17·49
75°	24·1	1,560	3·01
90°	−82·8	−5,349	−10·07
105°	−167·5	−10,820	−20·38
120°	−226·6	−14,640	−27·58
135°	−261·9	−16,920	−31·86
150°	−279·3	−18,040	−33·99
165°	−286·0	−18,480	−34·80
180°	−287·9	−18,580	−34·99

Clearance Volume of Engine Cylinders.—These were determined by filling the clearance spaces with water from a tank balanced on a weighing machine.

Clearance volume, " A " cylinder, ... 2·996 cubic feet.

,, ,, " B " ,, ... 2·740 ,, ,,

Clearance volume as per cent. of working stroke, " A " cylinder   27·12 per cent.

,, ,, ,, ,, ,, " B " ,,   24·77 ,, ,,

Clearance volume as per cent. of total volume, " A " cylinder   21·34 ,, ,,

,, ,, ,, ,, ,, " B " ,,   19·85 ,, ,,

Particulars of a 500-H.P. Gas-Engine (Premier) working with Mond Gas.

The engine, Plates 2 and 3, was made by the " Premier " Gas Engine Co., Sandiacre, near Nottingham, for Messrs. Brunner, Mond and Co. It is a two-cylinder engine of the " positive scavenger " type, arranged with the cylinders tandem fashion, and having a third piston which serves the double purpose of

pumping the scavenging air and acting as a guide or crosshead of large bearing
surface.   The motor pistons are of the " Premier " water-cooled type, and side-
rods are used to couple the back piston to the crosshead.   Only one connecting-rod
is required, and impulses are received from each motor cylinder alternately.   The
engine is direct connected by means of a " cheese " coupling to a Mather and
Platt dynamo, having a normal output of 2,250 ampères at 110 volts.

Engines :—Diameter of motor cylinders . . . 28⅓ inches.
    „   „   pump cylinder . . . 43½ „
    Stroke of all pistons . . . . 30 „
Speed :—Revolutions per minute (normal) . . 125

Weight of Reciprocating Parts :—
    Two motor pistons, pump piston, side rods, crosshead, and
        equivalent reciprocating portion of connecting-rod and
        water-service . . . . 8,925 lbs.
    Reciprocating weight per square inch of area of motor-pistons . 7·18 lbs.

Acceleration of Reciprocating Parts :—
    When the engine is running at its normal speed of 125 revolutions.

Crank angles from horizontal.	Acceleration in feet per sec. per sec.	Force producing acceleration in lbs.	Force in lbs. per square inch on the area of two pistons.
0°	258·7	71,685	57·69
15°	245·4	68,000	54·73
30°	207·7	57,553	46·32
45°	151·4	41,953	33·76
60°	84·75	23,483	18·90
75°	16·78	4,650	3·74
90°	− 44·60	−12,358	− 9·94
105°	− 94·03	−26,055	−20·27
120°	− 129·3	−35,829	−28·83
135°	−151·4	−41,953	−33·76
150°	−163·1	−45,195	−36·37
165°	−168·1	−46,580	−37·40
180°	−169·5	−46,968	−37·80

APPENDIX V.—TABLE 1.

Trial of the 400-H.P. Gas-Engine (Crossley) coupled direct to Dynamo (Appendix IV).

Both cylinders taking gas every cycle. No misses.	Trial at normal working load.		Trial at full load.	
Date of trial .	2 July 1900.		10 April 1900.	
Duration of trial .	2 hours		6 hours	
Average output of dynamo, ampères.	2208·0		2268·4	
volts .	98·6		110·0	
E.H.P. .	291·8		334·4	
Average revolutions per minute .	152·4		148·5	
Mean effective pressure, average for " A " and " B " cylinders .	51·37		60·43	
Average Indicated Horse-Power .	377·9		432·9	
Total Mond Gas as measured by meter, cubic feet .	49,640		176,820	
Gas used per hour, reduced to 0° C. and 760 m.m. .	22,711		27,162	
Analysis of dry gas :—				
CO_2 vol. per cent. .	14·5		15·0	
CO ,, ,, ,,	12·0		11·5	
H ,, ,, ,,	29·0		28·5	
CH_4 ,, ,, ,,	2·0		2·1	
N ,, ,, ,,	42·5		42·9	
Efficiency of dynamo, maker's figure, per cent. .	93		93	
Brake horse-power .	313·8		359·6	
I.H.P. absorbed in fluid resistances .	29·20		27·80	
,, ,, ,, engine friction .	34·90		45·53	
Total frictional losses, H.P. .	64·10		73·33	
Mechanical efficiency of engine :—				
excluding fluid losses .	90·76		89·48	
including fluid losses .	83·04		83·06	
Combined efficiency, E.H.P./I.H.P. per cent. .	77·23		77·25	
Mond gas used (cubic feet at 0° C.):—				
per I.H.P. hour .	60·09		62·74	
,, B.H.P. ,, .	72·37		75·53	
,, E.H.P. ,, .	77·82		81·22	
	Higher.	Lower.	Higher.	Lower.
Calorific value of gas (at 0° C.):—				
Kilo-calories per cubic mètre	1414·5	1287·9	1423·5	1268·3
B.T.U. per cubic foot .	162·2	144·6	159·9	142·5
Thermal efficiency, per cent. :—				
Calculated on the I.H.P. .	26·23	29·42	25·49	28·61
,, ,, ,, B.H.P. .	21·78	24·43	21·17	23·76
,, ,, ,, E.H.P. .	20·26	22·73	19·69	22·09

NOTE.—Between the two tests recorded above, the pistons were slightly reduced in diameter, giving greater freedom of working for the normal load trial; the exhaust pipes were also altered, so as to remove them to the outside of the building. More gas per stroke was used at full load, the quantity corresponding with greatest economy being exceeded.

APPENDIX V (continued).

TABLE 2.

Figures on the Cyclical Speed Variation of the same
400-H.P. Gas-Engine (Appendix IV).

This Table shows the results of integrating the speed-curve of Fig. 27 (page 61), and comparing the relative positions of the actual engine fly-wheel with an imaginary fly-wheel moving at a uniform angular velocity equal to the mean actual velocity.

Angular motion of standard fly-wheel.	Revolutions per minute of standard fly-wheel.	Speed of actual fly-wheel.		Angular motion of actual fly-wheel.	Difference in relative angular position of the two wheels.
		Average revolutions per minute during interval.	Average revolutions per minute from start of cycle.		
0°	150·564			start together	
90°	,,	150·18	150·18	89°·77	− 0°·23
180°	,,	150·47	150·325	179°·71	− 0°·29
270°	,,	150·675	150·442	269°·77	− 0°·23
360°	,,	151·10	150·606	360°·09	+ 0°·09
450°	,,	150·95	150·675	450°·32	+ 0°·32
540°	,,	150·66	150·672	540°·38	+ 0°·38
630°	,,	150·45	150·641	630°·31	+ 0°·31
720°	,,	150·03	150·564	finish together	

APPENDIX V (continued).

TABLE 3.

Speed Variation of the same 400-H.P. Gas-Engine under different conditions of Governing (Appendix IV).

Conditions.	Vibrations recorded per revolution.		Corresponding revolutions per minute.		Greatest total variation in speed.	Speed variation as per cent. on mean.	Speed variation from mean speed per cent.	Average number of revolutions between highest and lowest.
	Least Number.	Greatest Number.	Highest.	Lowest.				
Full load, both cylinders firing every time. 2,250 amperes, 106 volts	205·5	205·9	149·50	149·22	0·28	0·1875	0·0937	23
Both cylinders governing from large to small cams. Two charges on small to one on large; cam, small diagram 78 per cent. of large. 1,900 amperes, 100 volts	204·7	207·3	150·07	148·20	1·87	1·254	0·627	23
Both cylinders governing on "hit and miss" principle. 1,700 amperes, 100 volts	203·4	207·4	151·05	148·13	2·92	1·952	0·976	15
"B" cylinder firing every time, but "A" governing "hit and miss". 1,700 amperes, 100 volts	206·6	210·2	148·70	146·13	2·57	1·743	0·871	13
"A" cylinder firing every time, but "B" governing "hit and miss". 1,700 amperes, 100 volts	206·7	212·0	148·62	144·90	3·72	2·517	1·258	17
Slow speed experiment, "A" cylinder governing, "B" and gas shut off, being driven by "A". 500 amperes, 60 volts	309·5	323·3	99·26	95·02	4·24	4·364	2·182	12

NOTES.—The vibrations are those of a standard electrical timing-fork made by the Cambridge Scientific Instrument Co, and making 512 complete vibrations per second.

The gas-engine runs in parallel with other gas and steam-engines, and all engines are separately excited from one independent source. Current generated is used for electrolytic plant.

H 2

APPENDIX V (*continued*).

TABLE 4.

Speed Record during the Slowing Down of the 400-*H.P. Gas-Engine.*

These records were taken by the Tuning-fork Cyclometer, Plate 7.

The engine was run alone supplying current to the electrolytic plant, and after reaching a load rather above full normal load, both " A " and " B " governors were suddenly thrown out of gear, so that no more gas was supplied to the engine, which continued to be driven only by the energy stored in the fly-wheel. The power exerted during the short interval of measurement was equivalent to 410 I.H.P., calculated from the observed electrical output.

Period of measurement	8 revolutions.
Vibrations of tuning-fork	1648·4
Time occupied	3·22 seconds.
Speed fell from	152·83 revs. per min.
Speed fell to	145·65 ,, ,, ,,
Fall in speed equals	0·89 rev. per min. per rev.

Foot-lbs. of work (410 H.P. for 3·22 seconds) . . 726,110

Energy given up by fly-wheel :—

$$343·5 \{ (152·83)^2 - (145·65)^2 \} = 736,000,$$

which shows a very fair agreement.

TABLE 5.

Results of Tests made with a 500-*H.P. Gas-Engine* (*Premier*), *working with Mond Gas.*

Winnington Power-House, 7 December, 1900.

Trial with Engine giving Two-thirds of its Maximum Output.

Duration of test, 12.30 p.m. to 5.30 p.m. . . . . 5 hours.

Dimensions of Engine :—

Two cylinders arranged tandem, each . . .	28¼ ins. diam.
Pump cylinder, for scavenging air	43½ ins. diam.
Length of stroke	30 ins.

The engine is direct coupled to a Mather and Platt Dynamo.

Average revolutions per minute . . . . . 128·05
Load on engine, as fraction of maximum output . . $\frac{3}{4}$
Number of explosions per minute, back cylinder . . 64·02
   ,,   ,,   ,,   front   ,, . . 31·75
Mean effective pressure, average for back cylinder . 109·1 lbs. per sq. in.
   ,,   ,,   ,,   ,,   front   ,, . 107·4 ,, ,, ,,
   ,,   ,,   ,,   ,,   pump   ,, . 2·55 ,, ,, ,,
   ,,   ,,   ,, "bottom loop," back . . 2·25 ,, ,, ,,
   ,,   ,,   ,,   ,,   front . . 2·60 ,, ,, ,,
Indicated Horse-Power, back cylinder . . . 328·72
   ,,   ,,   front   ,, . . . 160·49
   ,,   ,,   gross total . . . 489·21
   ,,   ,,   pump . . . . 21·39
   ,,   ,,   "bottom loop," back . . 6·77
   ,,   ,,   ,,   ,,   front . . 7·83
   ,,   ,,   total fluid losses . . 35·99
Output of dynamo, average ampères . . . . 2320·0
   ,,   ,,   ,,   volts . . . . 110·1
Electrical Horse-Power . . . . . . 342·4
Kilowatts . . . . 255·43

Efficiencies :—

   Electrical efficiency of dynamo . . . . . 93 per cent.
   Mechanical efficiency of engine, excluding fluid losses. 81·22 per cent.
   Brake H.P. at dynamo coupling . . . . 368·2
   Total I.H.P. lost, including all frictional, fluid, and}
      pump losses . . . .} 121·0
Combined efficiency, E.H.P./I.H.P., per cent. . . 70·0
Average temperature of jacket water, back . . 49° C.
   ,,   ,,   ,,   ,,   front . . 37° C.

Gas used.—Total as measured by meter . . . . 136,100 cubic feet.
Temperature of gas 14°·6 C.   Barometer 29·992 inches.
Dry gas at 0° C. and 760 mm., used per hour . . . 25,482 ,, ,,

Analysis of Gas.—CO_2 16·0 vol. per cent.
                  CO   12·2 ,, ,,
                  H   27·8 ,, ,,
                  CH_4 2·2 ,, ,,
                  N   41·8 ,, ,,
   Total combustible gases, volume per cent. . . . 42·2
"Higher" calorific value, including latent heat of steam :—
   Kilo-calories per cubic mètre, 0° C. . . . 1,432·7
   British thermal units per cubic foot . . . 160·9
"Lower" calorific value, excluding latent heat of steam :—
   Kilo-calories per cubic mètre, 0° C. . . . 1,280·4
   British thermal units per cubic foot . . . 143·8

				cubic feet.	cubic mètres.
Mond Gas, at 0° C., per I.H.P. hour	.	.	.	52·09	1·475
,,	,,	,, B.H.P. hour	. .	69·20	1·959
,,	,,	,, E.H.P. hour	. .	74·42	2·107
,,	,,	,, per Board of Trade Unit .		99·76	2·825

Thermal efficiencies.	Calculated on "higher" calorific value.	Calculated on "lower" calorific value.
	per cent.	per cent.
Calculated on the I.H.P. . . .	30·38	34·00
B.H.P. . . .	22·87	25·59
E.H.P. . . .	21·27	23·80

TABLE 6.

Figures on the Cyclical Speed Variation
of the same 500-H.P. Gas-Engine (Appendix IV).

This Table shows the results of integrating the speed-curve of Fig. 32 (page 67), and comparing the relative positions of the actual engine fly-wheel with an imaginary fly-wheel moving at a uniform angular velocity equal to the mean actual velocity.

Angular motion of standard fly-wheel.	Revolutions per minute of standard fly-wheel.	Speed of actual fly-wheel.		Angular motion of actual fly-wheel.	Difference in relative angular position of the two wheels.
		Average revolutions per minute during interval.	Average revolutions per minute from start of cycle.		
0°	125·830			Start	together.
90°	,,	125·41	125·410	89·700°	− 0·30
180°	,,	126·47	125·940	180·157°	+ 0·16
270°	,,	126·16	126·013	270·392°	+ 0·39
360°	,,	125·28	125·830	360·000°	nil
450°	,,	125·47	125·758	449·742°	− 0·26
540°	,,	126·47	125·876	540·197°	+ 0·20
630°	,,	126·13	125·913	630·415°	+ 0·41
720°	,,	125·24	125·830	finish	together.

APPENDIX VI.

Copy of Report on the Official Trial of a 60-N.H.P. Gas-Engine (Crossley) coupled to Dynamo (Siemens No. 3574).

The trial of this combined set took place on 5th February 1897, at the Winnington Power-House. Mr. Bradley was present to represent Messrs. Crossley Brothers, and Mr. Collins to represent Messrs. Siemens Brothers.

The engine was started at 11.42 a.m., and ran without a stop until 5.30 p.m.

From the figures obtained I have made certain calculations, choosing for this purpose the figures of the last $2\frac{1}{2}$ hours of the trial, because during this period no adjustment of any valves was necessary, and all conditions remained constant.

The results are summarised as follows :—

Average speed of engine, revolutions per minute	162
Number of explosions per minute, " A " cylinder	67
,, ,, ,, " B " ,,	60
Number of explosions possible per minute for each	81
Proportion of misses to explosions	27·5 per cent.
Average temperature of jacket water, " A " cylinder	46° C.
,, ,, ,, " B " ,,	48° C.
Total Mond gas used during $2\frac{1}{2}$ hours	23,280 cubic feet.
Mond gas used per hour	9,312 ,, ,,
Mean effective pressure from Indicator Diagrams, " A " cylinder	82·1 lbs.
Mean effective pressure from Indicator Diagrams, " B " cylinder	80·0 ,,
Average total Indicated Horse-Power	141·6
Dynamo (working on resistance frames) :—	
Average ampères in main circuit	768
Average ampères in shunt	19·8
Average total ampères generated	787·8
Potential at dynamo terminals	100·0 volts.
Total Electrical Horse-Power	105·6
Useful Electrical Horse-Power	103·0
Mond gas used per I.H.P.-hour, cubic feet as measured	65·7
,, ,, ,, E.H.P. ,, ,, ,, ,,	88·1
,, ,, ,, ,, ,, (external circuit)	90·4
Taking 160,000 cubic feet per ton of coal at producers :—	
Coal used per I.H.P.-hour	0·92 lbs.
,, ,, ,, E.H.P. ,,	1·23 ,,
,, ,, ,, E.H.P. ,, (external circuit)	1·26 ,,
Temperature of armature at end of run, engine end	45° C. (113° F.)
,, ,, ,, ,, commutator end	41°·5 C. (106°·7 F.)
Temperature of engine room, average	19°·4 C. (66°·9 F.)
,, ,, field magnet coils, average	38°·0 C. (100°·4 F.)
,, ,, ,, ,, ,, at end of run	40°·8 C. (105°·4 F.)

Distribution of Power.—Assuming the efficiency of the dynamo to be 90 per cent., with a total I.H.P. generated of 141·6, we have :—

Energy expended in friction and used in driving fan to increase gas pressure . . . . }	24·3 H.P.
Lost in dynamo	11·7 ,,
Useful electrical power, in external circuit . . .	103 E.H.P.
Mechanical efficiency of engine, regarding the fan as part of the engine . . . . }	82·9 per cent.
Combined efficiency, ratio of E.H.P./I.H.P. . . .	72·7 ,, ,,
Thermal efficiency of gas-engine, calculated on I.H.P. .	26·85 ,, ,,

Remarks :—The engine ran smoothly and kept cool in all its bearings. It gave no trouble in any way, and the output is comfortably within its power. The dynamo ran sparkless and did not overheat in any of its parts. The average load was rather above its guaranteed load of 750 ampères and 100 volts.

(Signed)   HERBERT A. HUMPHREY.

APPENDIX VII.

Report on the Working of
the same 60-*N.H.P. Gas-Engine (Appendix VI).*

Engine.—Has two cylinders each 17 inches diameter by 24 inches stroke. The speed is 160 revolutions per minute.

Conditions.—The engine ran with Mond gas made from cheap bituminous fuel. All the gas used was measured through a large wet-meter. The engine is direct-coupled to a 75-kilowatt Siemens dynamo, supplying current to an electrolytic plant.

Hourly readings of the output, as shown by the ampères and volts at the switchboard, were regularly recorded day and night throughout the two years.

During 1898 the explosions were controlled by a "hit and miss" governor, but in 1899 the gas valve was throttled so as to give an explosion every time, but with a somewhat weaker mixture.

APPENDIX VII (*continued*).

TABLE 1.

Long Runs without Stopping.

The following continuous runs without stoppage have been made
during the years 1898 and 1899.

Period.			Number of days' (and nights') continuous run.	Hours.*
21 December 1897	to 20 March 1898	. .	90 days	2,160
2 April 1898	to 22 April 1898	. .	20 ,,	480
22 April 1898	to 28 May 1898	. .	36 ,,	864
28 May 1898	to 22 June 1898	. .	25 ,,	600
22 June 1898	to 22 July 1898	. .	30 ,,	720
13 August 1898	to 13 October 1898	. .	61 ,,	1,464
13 October 1898	to 30 December 1898	. .	78 ,,	1,872
31 January 1899	to 19 June 1899	. .	138 ,,	3,312
26 June 1899	to 7 September 1899	. .	73 ,,	1,752
8 September 1899	to 7 November 1899	. .	59 ,,	1,416
14 December 1899	to 25 April 1900	. .	131 ,,	3,144

* The odd hours, beyond complete days, have not been included.

APPENDIX VII (*continued*).

TABLE 2.

	Year 1898.	Year 1899.
Hours.—Total number of hours in year	8,760	8,760
Hours gas-engine ran on load	8,356·5	8,574·4
Hours running as per cent. on total	95·4	97·88
Units Generated.—1,000 watt-hours generated and measured at the switchboard	558,726	562,855
Gas Used.—Cubic feet of Mond gas supplied to the engine during the year, measured saturated at the temperature of the meter-house	64,281,240	67,349,650
Load.—Average ampères at 100 volts	668·5	656·5
Average E.H.P. at switchboard	89·6	88·0
Efficiency.—On the assumption that the electrical efficiency of the dynamo is 91 per cent., and the mechanical efficiency of the engine is 85 per cent., the combined efficiency will be 77·35 per cent., and the average I.H.P. for the year is	115·8	113·7
Consumption of Gas.—Per I.H.P. hour	66·4 c. ft.	69·0 c. ft.
or	1·88 m³	1·96 m³
or	1·03 lbs. slack	1·08 lbs. slack
Per kilowatt-hour at switchboard	115·0 c. ft.	119·6 c. ft.
or	3·25 m³	3·388 m³
or	1·79 lbs. slack	1·86 lbs. slack
Calorific Value of Gas, in kilo-calories :—		
Per cubic foot, as measured	38·2	37·5
Per cubic mètre, as measured	1,350	1,325
Thermal Efficiency :—		
Kilo-calories supplied per I.H.P.-hour	2,537	2,597
Efficiency calculated on I.H.P. per cent.	25·4	24·8
Kilo-calories supplied per kilowatt-hour	4,390	4,489
Efficiency calculated on kilowatts per cent.	19·7	19·2

NOTE.—The dynamo was separately excited, and the current for the field magnets is not included in the above figures. Isolated experiments show the combined efficiency to be somewhat less than that assumed above, so that the I.H.P. upon which the efficiency has been calculated is certainly not too high.

Actual Consumption of Oil for the Year 1899.

Oil used for the engine and dynamo during the year   .   . = 736 gallons.

Cost of this oil at 1s. 6d. per gallon   .   .   .   .   . 13,248 pence.

Board of Trade units of electricity generated 562,855

Cost of oil per unit   .   .   .   . 0·0235d.

NOTE.—With the new 400-H.P. gas-engine (Crossley) the cost of oil is only 0·0089d. per unit. The oil is collected, filtered, and used over and over again, only the loss being made up with fresh oil.

APPENDIX VIII.

Test of a Two-cylinder Gas-Engine (Westinghouse No. 103).

Size of engine, 11 inches by 12 inches.

Tested at shop (Westinghouse Machine Co., Pittsburg).

Tester's Record.—11 March 1899.

Kind of gas used, Natural gas. Meter No. 38,877. Barometer 29·4 inches.

	1	2	3	4
Pressure of gas at meter .	0·5 inch.			
Temp. of gas at meter . .	72° F.			
Brake circumference . .	25 ft.			
Total weight on scales . lbs.	360	275	160	0
Dead weight on scales . .	45	45	45	
Speed per minute . revs.	280	290	294	295
Time of start . . .	9–11–0	9–29–40	9–50–10	10–21–15
Time of finish . .	9–28–0	9 46–30	10–6–10	10–35–15
Duration of test . . mins.	17	16·83	16	14
Meter reading at start . .	2,890	3,110	3,290	3,430
Meter reading at finish . .	3,090	3,260	3,380	3,470
Gas according to meter . .	200	150	90	40
Gas per hour . . .	706	535	338	171
Gas per hour, corrected to 30 inches mercury and 62° F.	692	524	331	168
Brake Horse-Power . .	66·8	50·5	25·6	0
Cubic feet of gas per B.H.P. hour . . .	10·4	10·4	12·9	
Calorific value of gas . .	1,000 British Thermal Units per cubic foot.			
Thermal efficiency calculated on B.H.P. . .	24·6 per cent.	24·6 per cent.	19·8 per cent.	

(Signed)   SAMUEL LADLEY.

APPENDIX VIII (*continued*).

FIG. 36.   *Indicator Cards (full size) of Gas-Engine (Westinghouse No. 103).*
Taken 11 March 1899.

Spring $\frac{1}{240}$ 66·8 B.H.P.

1.

Spring $\frac{1}{240}$ 50·5 B.H.P.

2.

Spring $\frac{1}{240}$ 25·6 B.H.P.

3.

Spring $\frac{1}{80}$ Running Light.

4.

Power controlled by varying the quantity of explosive mixture, both gas and air per stroke.

Gas-Engines under construction, November 1899.

The following sets of gas-engines were in course of construction in the Westinghouse Machine Co.'s shops, Pittsburg, Pennsylvania, at the time of the author's visit in November 1899 :—

10 B.H.P. engines coming through the shops in lots of 24
25	,,	,,	,,	,,	,,	30
35	,,	,,	,,	,,	,,	18
60	,,	,,	,,	,,	,,	15
125	,,	,,	,,	,,	,,	12
310	,,	,,	,,	,,	,,	12
650	,,	,,	,,	,,	,,	2
1,500	,,	,,	,,	,,	,,	1

These figures show that this firm had in hand 6,420 B.H.P. of engines in units over 300 H.P. each, without counting smaller sizes.

APPENDIX IX.

Estimate for a 20,000-*E.H.P. Central Station Gas-Engine Plant worked with Mond Gas.*

Conditions of Working.—Mond Gas Producers and Recovery Plant worked in conjunction with gas-engines and dynamos. All extra steam raised by utilising the gas-engine exhaust-gas. The electric energy (1) consumed on the premises for an electrolytic plant, (2) transmitted a short distance and sold in bulk with a 50 per cent. load factor, or (3) with $33\frac{1}{3}$ per cent. load factor.

A gas-dynamo at full load takes 105 cubic feet of Mond gas, at 0° C. to give one unit (kilowatt-hour). Allowing for a somewhat reduced efficiency at part load, and for driving auxiliary machinery, &c., the liberal figure of 125 cubic feet per unit will be taken. Then 1 ton of coal will yield gas for 1,059 units, and it is assumed that 1,000 units are actually sold.

Output :—

Number of units sold per ton of slack gasified   .   1,000

Slack Cost per Unit sold (pence) :—

								d.
With slack at 3s. per ton	.	.	.	.	0·036
,,	,,	4s.	,,	,,	.	.	.	.	0·048
,,	,,	5s.	,,	,,	.	.	.	.	0·060
,,	,,	6s.	,,	,,	.	.	.	.	0·072
,,	,,	7s.	,,	,,	.	.	.	.	0·084
,,	,,	8s.	,,	,,	.	.	.	.	0·096
,,	,,	9s.	,,	,,	.	.	.	.	0·108
,,	,,	10s.	,,	,,	.	.	.	.	0·120

Working Producers, Recovery, and Sulphate Plant :—
    Cost of discharging and handling slack, working producers,
      recovery, and sulphate plant, and including administration,
      wages, repairs and maintenance, stores, acid, lighting, &c.
             Per ton of slack gasified .   .   .   .   .   3s. 6d.

Value of Sulphate Recovered :—
    At £10 per ton of sulphate, naked at works ; and with 25 tons
      of slack gasified, yielding 1 ton of sulphate of ammonia.
             Per ton of slack gasified .   .   .   .   .   8s.

Profit due to Sulphate Recovery :—
    Being credit for sulphate less working expenses.
             Per ton of slack gasified   .   .   .   .   4s. 6d.
             or per unit of electric energy sold   .   .   .   0·054d.

Net Cost of Mond Gas per Unit sold (pence) :—
                                                     d.
    With slack at 4s. 6d. per ton . .   .   .   .   .   0·000
    ,,   ,,   5s.   ,, ,, ...   0·006
    ,,   ,,   6s.   ,, ,, ...   0·018
    ,,   ,,   7s.   ,, ,, ...   0·030
    ,,   ,,   8s.   ,, ,, ...   0·042
    ,,   ,,   9s.   ,, ,, ...   0·054
    ,,   ,, 10s.   ,, ,, ...   0·066

	Load Factor.		
	100 per cent.	50 per cent.	33⅓ per cent.
Power Plant (pence per unit sold) :—			
Oil, waste, and petty stores . . .	0·030	0·030	0·030
Labour and attendance . . .	0·034	0·051	0·068
Repairs and maintenance. . .	0·036	0·058	0·077
Total Cost per Unit sold (pence) :—			
With slack at 3s. per ton . .	0·082	0·121	0·157
,, ,, 4s. ,, ,, . .	0·094	0·133	0·169
,, ,, 5s. ,, ,, . .	0·106	0·145	0·181
,, ,, 6s. ,, ,, . .	0·118	0·157	0·193
,, ,, 7s. ,, ,, . .	0·130	0·169	0·205
,, ,, 8s. ,, ,, . .	0·142	0·181	0·217
,, ,, 9s. ,, ,, . .	0·154	0·193	0·229
,, ,, 10s. ,, ,, . .	0·166	0·205	0·241
Capital Account :—			
(Producers and recovery plant only, and			
allowing 20 per cent. reserve on all plant)			
Slack handling, regenerator plant, and gas producers	£26,500	£26,500	£26,500
Acid towers, recovery and sulphate plant .	23,500	18,700	17,100
Steam-raising plant and sundries . .	19,000	19,000	19,000
Total	£69,000	£64,200	£62,600

NOTE.—No charges on capital account, rent, rates, or taxes, are included in
the above figures. (See remarks in body of Paper, page 70.)

APPENDIX X.

Notes on Heat Consumed
in Steam and Gas-Engines, Fig. 24 *(page* 57*)*.

Case I.—The fuel used is here taken at 6 lbs. per unit. This is a very good result for an electric light station.

Case II.—Professor Kennedy's ideal figures are :—

10¼ lbs. of water evaporated per lb. of coal.

8½ lbs. of steam at engine per lb. of fuel burnt.

16 lbs. of steam give one I.H.P. hour.

Combined efficiency of engine and dynamo at ¾ full load is 77 per cent.

Case III.—These figures are based on Professor Unwin's estimate of 2·1 lbs. of coal per B.H.P. hour for continuous work. An evaporation of 9 lbs. of steam per lb. of coal, a 5 per cent. loss, and a dynamo efficiency of 93 per cent.*

Case IV.—The slack used in Mond producers costs about 2s. 6d. per ton at the pit, when prices are normal. Delivered at Winnington works the cost is about 6s. 9d., and, as the gas producers are worked as a separate department, this price is charged to the gas-engines for the gas from one ton of slack, the profit on by-products (after paying the cost of working the producers, &c.) being retained by the department. In the diagram, Fig. 24, fuel has been taken at 5s. per ton as an intermediate figure, making some allowance for the above fact. If exhaust steam is not available for use in the Mond producers and live steam has to be raised in steam boilers, then 20 to 25 per cent. should be added to the amount and cost of the fuel.

Heat Consumed to Produce One Kilowatt-hour of Electric Energy at Switchboard.

Calorific value of coal taken at 7,900 Centigrade heat-units.

Calorific value of slack taken at 6,786   Do.   do. do. (on dry sample).

Price of coal taken at 12s. per ton.

Price of slack taken at 5s. per ton.

Heat in 1 lb. of steam at 180 lbs. pressure = 666 lbs. Centigrade heat-units.

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* "Development and Transmission of Power," Unwin, page 64, 1893 edition.

	Coal used per k.w. hour.	Steam at engine per k.w. hour.	Heat-units in coal.	Heat-units in steam or gas.	Cost of fuel per k.w. hour.
	Lbs.	Lbs.			d.
Steam.					
Case I.—Central station (good actual)	6	42	47,400	27,970	0·385
Case II.—Central station (ideal)	3·277	27·85	25,888	18,548	0·210
Case III.—Continuous running (ideal).	3·027	25·88	23,913	17,236	0·194
Gas.					
Case IV.—Actual results .	1·79		11,520	9,675	0·048
Actual fuel cost for 83 electric supply stations (on units sold, year 1898) .					0·778

APPENDIX XI.

Precautions taken to ensure accuracy in Author's Experimental Results.

Measurement of Gas.—It was decided that the only satisfactory method of measuring the volume of gas used by the gas-engine was to employ a wet-meter of large capacity, and to calibrate it at varying speeds by the falling of a gasometer. This plan was adopted, and a wet-meter of 50,000 cubic feet per hour capacity was installed, so that its working rate was one-half its ordinary capacity. Also, in spite of the expense, a gasometer to contain 7,000 cubic feet was erected, but was not finished in time for use during the experiments recorded in this Paper. Under these circumstances the makers of the meter were called upon to furnish a standard testing meter and to compare the readings when both meters were run in series. This was sufficient to prove the accuracy of the meter for low speeds, and the makers guaranteed that the record at working speeds could be relied upon.

Gas volumes, as measured by meter, were corrected for temperature, saturation, and pressure.

Indicator Diagrams.—In all eight indicators were used. Messrs. Crossley Brothers sent two Richards indicators modified by Casartelli. The author used three new Crosby indicators, and two new Richard-Darke indicators specially made to order by Elliott Brothers. Also Professor Burstall kindly lent his Wayne indicator, the springs of which had been carefully calibrated. The springs of the Crosby indicators were tested by Messrs. Willans and Robinson, and a certificate obtained of the slight errors observed. Independently the author had the springs tested again after the experiments were finished, and checked by a dead weight gauge-testing apparatus.

It was found unnecessary to correct the indicator diagrams for errors due to the reducing gear, this being so arranged that the error was negligible. The area of the diagrams was found either with the planimeter or by the method of dividing lines. Where average pressures at corresponding points of a large number of cards were required the latter method was used, although not quite so accurate.

In deference to the usual custom, the top loop only of the diagram was taken as representing the work done, the bottom loop being regarded as fluid resistance to be included in the frictional losses of the engine. This is scarcely a rational method, and the author takes this opportunity of protesting against it.

The author intended to use two continuous indicators. Although expensive and well-made instruments, they were found unreliable at 150 revolutions per minute; and he has found difficulty in obtaining a really good continuous indicator.

Speed of Engine.—A Harding's five-figure rotation counter, directly attached to the dynamo shaft, was used to record the revolutions of the engine. Two reciprocating counters automatically recorded the explosions at each end. These only operated when the gas valves were opened. Time was taken with a non-magnetic watch made by S. Smith & Son, of London, and known to be reliable. Changes of speed were measured by the "Cyclometer," Plate 7, the standard electrical tuning-fork of which made 512 complete vibrations per second.

Electrical Measurements.—The instruments used are those permanently attached to the main switchboard. The current was measured by a new Kelvin ampère-gauge, and the volts by a Kelvin electrostatic multicellular volt-meter. The latter was checked by a standard Siemens universal instrument and also by a Weston type volt-meter.

The main current was checked by the addition of the three branch currents, each of which was measured separately. The branch ammeters were themselves tested against a Kelvin ampère-balance of 1,500-ampère capacity, mounted on a special deep, isolated foundation in the engine-house.

Gas Analysis.—The samples of gas were taken at the meter. They were large aspirator samples, and the water displaced was acidified to prevent any absorption of CO_2. Samples were tested in the work's private laboratory, and the analysis certified by the chief chemist.   I

APPENDIX XII.

Table of Gases Saturated with Water Vapour at 760 mm. Pressure,
and at Temperatures from 0° to 99° C.

Temperature t° Centigrade.	Water vapour tension in mm. of mercury.	Grammes of Water Vapour absorbed by one cub. mètre of dry gas at 0° C. when saturated at t° C. and 760 mm.	Relative Volumes of dry gas and water vapour in a saturated mixture at t° C. and 760 mm.		Total Volume of Gas and Water Vapour resulting from saturating one cub. mètre of dry gas at 0° and 760 mm. to t° C.
			Dry gas per cent.	Water Vapour per cent.	
0	4·569	4·866	99·40	0·60	1·0060
1	4·909	5·231	99·36	0·64	1·0107
2	5·272	5·620	99·31	0·69	1·0144
3	5·658	6·035	99·26	0·74	1·0191
4	6·069	6·477	99·20	0·80	1·0228
5	6·507	6·948	99·14	0·86	1·0275
6	6·971	7·448	99·08	0·92	1·0312
7	7·466	7·983	99·02	0·98	1·0359
8	7·991	8·550	98·95	1·05	1·0407
9	8·548	9·153	98·88	1·12	1·0444
10	9·140	9·794	98·80	1·20	1·0491
11	9·767	10·47	98·71	1·29	1·0539
12	10·432	11·20	98·63	1·37	1·0587
13	11·137	11·97	98·53	1·47	1·0634
14	11·884	12·78	98·44	1·56	1·0682
15	12·674	13·64	98·33	1·67	1·0730
16	13·510	14·56	98·22	1·78	1·0778
17	14·395	15·53	98·11	1·89	1·0826
18	15·330	16·56	97·98	2·02	1·0884
19	16·319	17·66	97·85	2·15	1·0933
20	17·363	18·81	97·72	2·28	1·0981
21	18·466	20·04	97·57	2·43	1·1040
22	19·630	21·33	97·42	2·58	1·1099
23	20·858	22·70	97·26	2·74	1·1148
24	22·152	24·16	97·09	2·91	1·1207
25	23·517	25·69	96·91	3·09	1·1267
26	24·956	27·32	96·72	3·28	1·1327
27	26·470	29·03	96·52	3·48	1·1387

Temp. C.°	Water Vapour.		Relative volumes.		Total volume.
	Tension mm.	Grammes.	Dry Gas per cent.	Water Vapour per cent.	Gas and Water Vapour.
28	28·065	30·85	96·31	3·69	1·1447
29	29·744	32·77	96·09	3·91	1·1518
30	31·510	34·80	95·85	4·15	1·1578
31	33·366	36·95	95·61	4·39	1·1650
32	35·318	39·21	95·35	4·65	1·1722
33	37·369	41·61	95·08	4·92	1·1794
34	39·523	44·14	94·80	5·20	1·1866
35	41·784	46·81	94·50	5·50	1·1939
36	44·158	49·63	94·19	5·81	1·2023
37	46·648	52·61	93·86	6·14	1·2096
38	49·259	55·76	93·52	6·48	1·2181
39	51·996	59·09	93·16	6·84	1·2266
40	54·865	62·60	92·78	7·22	1·2363
41	57·870	66·32	92·39	7·61	1·2448
42	61·017	70·24	91·97	8·03	1·2545
43	64·310	74·38	91·54	8·46	1·2643
44	67·757	78·75	91·08	8·92	1·2753
45	71·362	83·38	90·61	9·39	1·2863
46	75·131	88·26	90·11	9·89	1·2974
47	79·071	93·43	89·60	10·40	1·3085
48	83·188	98·89	89·05	10·95	1·3208
49	87·488	104·67	88·49	11·51	1·3332
50	91·978	110·78	87·90	12·10	1·3468
51	96·664	117·25	87·28	12·72	1·3605
52	101·554	124·10	86·64	13·36	1·3742
53	106·655	131·35	85·97	14·03	1·3892
54	111·973	139·03	85·27	14·73	1·4054
55	117·516	147·17	84·54	15·46	1·4218
56	123·292	155·80	83·78	16·22	1·4394
57	129·310	164·97	82·99	17·01	1·4571
58	135·575	174·70	82·16	17·84	1·4761
59	142·097	185·03	81·30	18·70	1·4963
60	148·885	196·02	80·41	19·59	1·5179
61	155·946	207·72	79·48	20·52	1·5396
62	163·289	220·18	78·51	21·49	1·5639
63	170·924	233·46	77·51	22·49	1·5883

Temp. C.°	Water Vapour.		Relative volumes.		Total volume.
	Tension mm.	Grammes.	Dry Gas per cent.	Water Vapour per cent.	Gas and Water Vapour.
64	178·858	247·63	76·47	23·53	1·6152
65	187·103	262·77	75·38	24·62	1·6436
66	195·666	278·97	74·25	25·75	1·6733
67	204·559	296·32	73·08	26·92	1·7044
68	213·790	314·92	71·87	28·13	1·7381
69	223·369	334 91	70·61	29·39	1·7746
70	233·208	356·41	69·30	30·70	1·8137
71	243·616	379·59	67·95	32·05	1·8556
72	254·305	404·62	66·54	33·46	1·9002
73	265·385	431·71	65·08	34·92	1·9488
74	276·868	461·09	63·57	36·43	2·0002
75	288·764	493·04	62·00	38·00	2·0570
76	301·086	527·88	60·38	39·62	2·1179
77	313·846	565·99	58·70	41·30	2·1843·
78	327·055	607·81	56·97	43·03	2·2574
79	340·726	653·86	55·17	44·83	2·3386
80	354·873	704·79	53·31	46·69	2·4268
81	369·508	761·36	51·38	48·62	2·5245
82	384·643	824·50	49·39	50·61	2·6344
83	400·293	895·38	47·33	52·67	2·7566
84	416·472	975·45	45·20	54·80	2·8939
85	433·194	1066·5	43·00	57·00	3·0516
86	450·473	1171·0	40·73	59·27	3·2298
87	468·324	1291·9	38·38	61·62	3·4381
88	486·764	1433·4	35·95	64·05	3·6792
89	505·806	1601·0	33·45	66·55	3·9666
90	525·468	1802·7	30·86	69·14	4·3102
91	545·765	2049·7	28·19	71·81	4·7329
92	566·715	2359·1	25·43	74·57	5·2596
93	588·335	2757·5	22·59	77·41	5·9393
94	610·643	3289·6	19·65	80·35	6·8433
95	633·657	4035·4	16·62	83·38	8·1121
96	657·396	5155·2	13·50	86·50	10·017
97	681·879	7022·9	10·28	89·72	13·192
98	707·127	10,760·7	6·96	93·04	19·544
99	733·160	21,978·4	3·53	96·47	38·604
100	760·000	∞			∞

APPENDIX XIII.

Trials on the Continent of " Simplex " Gas-Engines.

No paper dealing with large gas-engines would be in any way complete without special reference to the gas-engines designed by M. Delamare-Deboutteville, and made, formerly by MM. Matter et Cie., Rouen, and recently by the Société Anonyme John Cockerill, Seraing, Belgium.

In 1897 the author saw the 300-H.P. "Simplex" gas-engine working at Pantin, and two 250-H.P. gas-engines at Truffaut; in the year 1900 he had the opportunity of studying the working of the 200-H.P. and the 600-H.P. gas-engines at Seraing. The illustration, Plate 8, shows a similar 600-H.P. engine at the Paris Exhibition. Trials of all these engines have been made; and from the very complete data given to the author he has abstracted the following important results, dealing, however, only with those experiments of recent date in which blast-furnace gas was the fuel employed.

In 1895 an experiment was made at the Cockerill Co.'s Works with an 8-H.P. "Simplex" engine, in order to determine the practicability of utilising high blast-furnace gas as fuel. The success was sufficient to induce the company to build a 200-H.P. gas-engine, which was started in April 1898, and officially tested by Professors Witz and Hubert in the following July.

The first 600-H.P. single-cylinder gas-engine was started at Seraing on 20 November 1899, and so rapid and remarkable has been the development that forty-six similar engines were in course of construction, or on order at the end of April 1900, besides three engines of 1,200 H.P. (page 107) and a number of smaller engines. The Cockerill Co. and M. Delamare-Deboutteville have now decided to build engines of 2,500 H.P. (page 107). The orders, amounting to 35,000 H.P. in less than a year, will be distributed among the large Continental firms which have secured licenses to manufacture "Simplex" gas-engines. These firms include Creusot Co. in France, Breitfeld and Danek in Austria, the Société Alsacienne at Mulhouse, and the Markische Maschinen Anstalt in Westphalia.

Experiments with a 200-H.P. " Simplex " Gas-Engine at Seraing, by Professor Aimé Witz.

The object of the experiments was to study the practical working conditions of a single-cylinder, Otto cycle, gas-engine of considerable power, using coke blast-furnace gases, and for this purpose it was essential to extend the trial over a sufficient period of time to cover the variations in quality, richness, and pressure of the gas, and to determine the consumption of water in the gas-washing plant, and the quantity of oil used for lubrication.

Dimensions of the Engine :—

Diameter of cylinder . . . 800 mm. (31·5 inches).
Stroke of piston . . . . 1·00 m. (39·37 inches).
Normal revolutions per minute . 105
Preliminary compression . . 7·5 kg. per cm.^{2} (106·6 lbs. per sq. inch).
Normal brake H.P. . . . 200 (or 197).

The gas was supplied from four blast-furnaces, either direct, or by passing it through a gas-holder of 300 cubic mètres (10,595 cubic feet) capacity. The power was absorbed by a rope brake having a water-cooled pulley 1·5 m. (59 inches) diameter. The revolutions and gas-admissions were counted by meters, and a Richard apparatus registered the speed-curve and showed a variation of 2·09 revolutions per minute. Indicator cards, readings of temperatures, load on brake, &c., were taken at half-hour intervals.

The quantity of water sent to the cylinder and scrubbers was measured by means of gauged tanks. The volume of gas used was measured by means of the fall of a gasometer, as read on three vertical scales placed 120° apart. Each measurement lasted twenty-nine minutes.

Date of test . . . . . 19 and 20 July 1897.
Duration of test . . . . Twenty-four hours.
Average speed . . . . . 105·2 revs. per minute.
Net load on brake . . . 1595·45 kg. (3517·33 lbs.)
Average B.H.P. . . . . 181·16 (178·6)
Average number of admissions . . 47 per minute.
Proportion of actual to possible number } 89·3 per cent.
    of admissions . . . . }
Average mechanical efficiency . . 85 per cent.
Temperature of air . . . 27°, 15°, 17·5° C.
Temperature of gas . . . 27°, 18°, 21° C.
Inlet temperature of jacket water . 22·7° C.
Outlet   ,,   ,,   ,, . 33·7° C.
Barometer . . . . . 765–770 mm. (30 inches.)

Consumption of Water :—

	litres.	gals.
For scrubbers, per hour . . .	5,388	1185·3
,, ,, per m.^{3} of gas, about	9	1·98
,, ,, per B.H.P. hour . .	30	6·6
For cylinder, per hour. . . .	13,000	2860·0
,, ,, per B.H.P. hour, about .	72	15·8
Total consumption of water } per B.H.P. hour, about . . }	102	22·4

Consumption of Oil and Grease :—

							lbs.
Per 24 hours, oil	.	.	.	.	68 kg.	149·9
„ „ grease	.	.	.	.	2 kg.	4·4
Per B.H.P. hour, oil	.	.	.	.	15 g.	0·033
„ „ „ grease	.	.	.	2·3 g.	0·005

Consumption of Gas (average of 5 tests):—

Volume of gas consumed per hour, reduced to 0° C. and 760 mm. .	605 m³ (21,362 cub. ft.)
Load on brake	1597·7 kg. (3521·3 lbs.)
Speed, revolutions per minute . .	105·47
Brake horse-power	181·82 (179·2)
Calorific value of one m.³ of gas, at 0° C. and 760 mm., assuming complete combustion at constant volume	981 kilo-calories (110·2 B.T.U. per cub. ft.)
Consumption of gas per B.H.P. hour .	3·329 m³ (119·2 cub. ft.)
Thermal efficiency (on B.H.P.) . .	19·4 per cent.

Experiments with a 600-H.P. " Simplex " Gas-Engine at Seraing, by Professor Hubert, of Liège University.

The engine was designed by M. Delamare-Deboutteville and built by the Cockerill Co. It is a single-cylinder engine, working on the Otto cycle, and direct coupled to a double-acting blowing cylinder.

Engine :—

Diameter of piston	1·30 m. (51·19 inches).
Stroke of piston	1·40 m. (55·13 inches).
Diameter of piston-rod . . .	0·244 m. (9·61 inches).
Diameter of shaft	0·460 m. (18·11 inches).
Space occupied, height above ground .	4·0 m. (13·1 feet).
„ „ length „ „ .	11·0 m. (36·1 feet)
„ „ width „ „ .	6·0 m. (19·7 feet).
Normal compression per cm². . .	9·5 kg. (135 lbs. per sq. in.).
Weight of fly-wheel	33·0 tonnes (32·5 tons).
Total weight, including fly-wheel .	127 tonnes (124·9 tons).

Blowing Cylinder :—

Diameter of cylinder. . . .	1·700 m. (66·94 inches).
Stroke of piston	1·400 m. (55·13 inches).
Diameter of piston-rod . . .	0·244 m. (9·61 inches).

Valves $\begin{cases}$ Corliss on one face. \\ Lang-Horbiger on other face. $\end{cases}$

Space occupied, height above ground .		.	.	4·0 m. (13·1 feet).
,,	,,	length .	. .	5·50 m. (18·0 feet).
,,	,,	width	. .	3·50 m. (11·5 feet).
Weight of blowing-engine .		.	.	31 tonnes (30·5 tons).

Dimensions and weight of combined set :—

Height above ground		. .	4·0 m. (13·1 feet).
Length			16·5 m. (54·1 feet).
Width			6·5 m. (21·3 feet).
Total weight			158 tonnes (155·5 tons).

Conditions of Tests :—

20 March 1900.—The blowing cylinder was uncoupled from the motor, and the shaft of the latter was connected, by means of a coupling, to a provisional shaft carrying a brake-wheel.   21 March.—The brake was removed and the blowing engine coupled to the motor, the compressed air being used to feed the blast-furnaces.

During the tests the motor received gas from 5 blast-furnaces, 4 of which were 18·4 m. (60·35 feet) high, the production of each one averaging 80 to 90 tons of pig-iron per day; the fifth furnace, 24 m. (78·7 feet) high, had a daily production of about 210 tons.

The gas was freed from the heavier dust by its passage through the ordinary deposit chambers, but before being sent to the motor it was passed through a special apparatus of about 70 m.³ (2,472·1 cubic feet) capacity, consisting of a wrought-iron box fitted with checker-work, and in which four 10 mm. (0·39 inch) Koerting injectors delivered sprays of water.

The cool washed gas was supplied to the motor either direct from the mains or through a pipe connected to the 300 m.³ (10,595 cubic feet) gas-holder used by Professor Witz for the previous experiments.   The small size of the holder limited the actual period of each measurement of gas to 7 minutes only, and it required 20 minutes for a small rotary blower, driven by an electric motor, to fill the holder again, during which time no measurement was possible.

The calorific value of the gas at constant volume was determined by means of a bomb calorimeter by Professor Witz, who was present on 20 March; also, for the two days of the trial, the calorific value of the gas at constant pressure was determined with a Juncker calorimeter.

A Crosby indicator was used for indicating the gas-engine, and two Thompson indicators were employed to ascertain the work of the blowing-engine.

The brake used on 20 March was a water-cooled pulley 3·01 m. (9·87 feet) diam., keyed upon a shaft of 160 mm. (6·3 inches) diam. and 3 m. (9·84 feet) long, carried upon two special bearings placed 1·4 m. (4·6 feet) apart. Three mine cables made of aloes, having a thickness of 32 mm. (1·26 inches) and a breadth of 0·20 m. (0·66 foot) were passed over the top half of the pulley, and were loaded to absorb the power. The unloaded ends were attached to a spring balance.

A Schmidt meter was used to determine the quantity of water passed through the engine jacket.

Governing was on the "hit-and-miss" principle.

The various readings were taken every five minutes where possible, during the actual period of measurement of the gas. To eliminate the influence due to the energy stored in the fly-wheel, the average number of revolutions was determined, each time, by taking a longer period than the duration of the gas-holder observations.

After the experiments on 20 March the full dynamometer load was instantaneously thrown on and off several times, and the speed variation did not exceed 3 per cent.

On 21 March, also after the trials, the air-blast pressure from the blowing cylinder was increased from 450 to 600 mm. (18 to 24 inches), causing the speed of the motor to fall from 94·2 to 62 revolutions, while the average pressure in the motor cylinder rose from 4·79 to 5·67 kg. per cm.^{2} (68 to 81 lbs. per sq. inch), thus demonstrating the power of the motor to exert a greater turning moment at a reduced speed—a result contrary, perhaps, to the general impression.

Fig. 38. *Indicator Diagrams taken from the 600-H.P. "Simplex" Blowing Engine, Seraing, 21 March 1900.*

Gas Motor Cylinder.   Air Cylinder (front).   Air Cylinder (back).

Tables 2 and 3 (pages 108 to 115) give the results of the two days' trials, but do not include the thermal efficiencies, which are as follows :—

Brake Tests (20 March 1900) :—

Calorific value of 1 cubic mètre of gas at 0° C. and 760 mm.

	Kilo-calories.	B.T.U. per cub. ft.
By Juncker's calorimeter .	915·2	102·8
By bomb calorimeter .	984·4	110·6

	Juncker.	*Bomb.*
	Per cent.	Per cent.
Tests Nos. 1–5, thermal efficiency on I.H.P.	27·16	25·25
Full load trial	27·11	25·20
Nos. 1–5, thermal efficiency (on B.H.P.)	—	18·46
Full load	—	20·48

Tests with Engine coupled to Blowing Cylinder :—

Calorific value of 1 cubic mètre of gas at 0° C. and 760 mm., 21 March.
By Juncker's calorimeter—

		B.T.U.
	Kilo-calories.	per cub. ft.
First series of experiments	876·25	98·44
Second series ,,	888	99·75
By bomb calorimeter—		
First series of experiments	991	111·3
Second series ,,	1004·3	112·8

Thermal Efficiency :—

	Juncker.	*Bomb.*
	Per cent.	Per cent.
Thermal efficiency on I.H.P., 1st series	30·92	27·34
,, ,, ,, 2nd series	30·66	27·11
Thermal efficiency on work in compressed air :		
1st series	23·29	20·60
2nd series	25·07	22·17

On 19 March the motor was run empty at 67·5 revolutions per minute, and the power absorbed was found to be 147·36 I.H.P.

Considering the full-load trials, and adopting a calorific value for the gas intermediate between that at constant pressure and at constant volume, Professor Hubert gives the following approximate balance sheet of heat quantities :—

		Per cent.
Heat converted into work in the cylinder		28
Heat carried away by circulating water		52
Heat carried away by gases and losses		20

APPENDIX XIII.—Table 1.

Large " Simplex " Gas-Engines.

(Designed by MM. Delamare-Deboutteville and Cockerill.)

Works.	Kind of Engine.	Number of of Engines.	H.P. of each Engine.	Total Horse-Power.
Rœchling'sche Eisen Und Stahlwerke Bei Dieden-hofen (Lorraine).	Double-cylinder tandem engines directly attached by tail rod to blowing cylinder.	3	1,200	3,600
Société Anonyme de Hauts-Fourneaux, Forges et Charbonnages de Differdange, Dannenbaum (Grand Duché du Luxembourg).	Six single cylinder engines direct coupled to blowing cylinders. Three single cylinder engines direct coupled to dynamos.	9	600	5,400
Proposed Central Electric Station.	Two tandem cylinders on each side of dynamo, giving 4 cylinders per engine.	4	2,500	10,000

APPENDIX XIII.—Table 2 (*continued on opposite page*).

(Brake Trials.)

Results of Tests made with a 600-H.P. Gas-Engine,
working with blast-furnace gas.
(*MM. Delamare-Deboutteville and Cockerill.*)

20 March 1900.

No.	Time.	Average height of Indicator cards.	Number of Admissions per minute.	I.H.P. (French)
		Millimètres. *Inches.*		
1	1.24 p.m.	7·100 0·279	41·50	792·61
2	2.12 p.m.	7·075 0·278	43·50	827·88
3	4.23 p.m.	6·913 0·272	42·27	786·05
4	4.52 p.m.	6·964 0·274	40·93	766·75
5	5.21 p.m.	6·936 0·273	41·60	776·17
6	5.51 p.m.	6·642 0·261	46·22	825·81
7	Average of Nos. 1 to 5.	6·998 0·276	41·96	789·89
8	{ Average calculated on the total duration of the first five tests. }	6·975 0·274	41·90	786·16

TABLE 2.—APPENDIX XIII.

(BRAKE TRIALS.)

Results of Tests made with a 600-H.P. Gas-Engine,
working with blast-furnace gas.
(MM. Delamare-Deboutteville and Cockerill.)

20 March 1900.

Tangential effort upon Brake.	Average Revolutions per minute.	Brake Horse-Power.	Mechanical Efficiency of Engine.
Kg. *Lbs.*			Per cent.
2872 6318	94·17	574·40	72·47
2857 6285	97·50	591·60	71·46
2877 6329	93·33	570·26	72·54
2872 6318	91·93	560·82	73·14
2850 6270	93·92	568·47	73·24
3386 7449	93·20	670·02	81·12
2865·6 6304·3	94·17	573·11	72·56
2869 6312	94·37	575·00	73·14

APPENDIX XIII.—Table 2 (*continued on opposite page*).

(Brake Trials.)

*Results of Tests made with a 600-H.P. Gas-Engine,
working with blast-furnace gas.
(MM. Delamare-Deboutteville and Cockerill.)*

20 March 1900.

No.	Time.	Volume of Gas used per Minute (at 0° C. and 760 mm.).	Consumption of Gas per hour.	
			Per I.H.P. (French)	Per B.H.P. (French)
		Cub. Mètres.	Cub. Mètres.	Cub. Mètres.
		Cub. Feet.	*Cub. Feet.*	*Cub. Feet.*
1	1.24 p.m.	32·070 / 1132·6	2·428 / 85·75	3·350 / 118·31
2	2.12 p.m.	35·028 / 1237·2	2·540 / 89·71	3·552 / 125·45
3	4.23 p.m.	33·549 / 1184·8	2·560 / 90·41	3·530 / 124·67
4	4.52 p.m.	32·968 / 1164·3	2·580 / 91·12	3·527 / 124·56
5	5.21 p.m.	33·866 / 1196·1	2·618 / 92·46	3·574 / 126·22
6	5.51 p.m.	35·250 / 1245·0	2·560 / 90·41	3·156 / 111·46
7	Average of Nos. 1 to 5.	33·496 / 1183·0	2·544 / 89·85	3·506 / 123·82
8	{ Average calculated on the total duration of the five first tests. }	33·496 / 1183·0	2·556 / 90·27	3·495 / 123·43

TABLE 2.—APPENDIX XIII.

(BRAKE TRIALS.)

Results of Tests made with a 600-H.P. Gas-Engine,
working with blast-furnace gas.
(*MM. Delamare-Deboutteville and Cockerill.*)

20 March 1900.

Consumption. of Water per B.H.P. hour.		Average Temperature of Cylinder Water.		Average Temperature of Gases.	
At Cylinder.	At Piston.	Inlet.	Outlet.	Inlet.	Outlet.
Litres. Gallons.	Litres. Gallons.				
56·8 12·5	12·7 2·8	7·86° C. 46·15° F.	33·17° C. 91·71° F.	9° C. 48·2° F.	508·5° C. 947·3° F.

APPENDIX XIII.—Table 3 *(continued on opposite page)*.

Further Results of Tests with a 600-H.P. Gas-Engine.
Trials with Engine coupled to Blowing Cylinder.
21 March 1900.

No.	Time.	Average height of Indicator cards.	Number of Admissions per minute.	I.H.P. (French)	Average height of Card from Blowing Cylinder.
		Mm. Inches.			Mm. Inches.
			FIRST SERIES.		
1	10.17 a.m.	7·89 0·31	34·27	727·35	26·30 1·03
2	10.44 ,,	7·74 0·30	37·12	772·86	28·20 1·11
3	11.13 ,,	7·72 0·30	37·47	778·13	28·20 1·11
4	11.41 ,,	7·76 0·31	35·47	740·41	28·90 1·14
5	12.16 p.m.	7·12 0·28	37·20	712·49	27·25 1·07
Arithmetical averages		7·646 0·301	36·306	746·21	27·77 1·09
Averages from combined observations				746·73	
			SECOND SERIES.		
6	2.4 p.m.	7·06 0·28	46·00	873·59	33·45 1·32
7	2.32 ,,	7·00 0·27	46·00	866·18	32·40 1·28
8	3.3 ,,	7·26 0·29	46·25	903·22	32·25 1·27
9	3.33 ,,	7·01 0·27	47·20	890·05	31·75 1·25
10	4.7 ,,	7·10 0·28	47·09	899·37	31·65 1·25
Arithmetical averages		7·086 0·279	46·51	886·48	32·30 1·27
Averages from combined observations				886·54	

TABLE 3.—APPENDIX XIII.

Further Results of Tests with a 600-H.P. Gas-Engine.
Trials with Engine coupled to Blowing Cylinder.
21 March 1900.

Average number of Strokes of Blowing Piston per minute.	H.P. in Air Compressed.	Average Pressure of Air in mm. of Mercury.	Mechanical Efficiency of the System.	Volumes of Gas consumed per Minute (at 0° C. and 760 mm.)
			Per cent.	Cub. Mètres. Cub. Feet.
		FIRST SERIES.		
164·6	522·60	392	71·85	28·265
170·6	580·67	395	75·13	998·31 29·512
170·0	578·63	404	74·36	1042·35 30·011
164·7	574·51	404	77·59	1059·98 29·149
169·3	556·84	388	78·15	1029·53 29·013
167·84	562·55	394	75·41	1024·73 29·190
	562·57		75·33	1030·98
		SECOND SERIES.		
184·00	743·07	451	85·06	33·748
184·00	719·50	450	83·07	1191·97 33·852
185·00	720·13	453	79·73	1195·64 34·684
188·8	723·52	448	81·29	1225·03 35·152
188·4	719·73	449	80·03	1241·56 34·996
186·04	725·57	450	81·81	1236·05 34·487
	725·30		81·01	1218·08

APPENDIX XIII.—TABLE 3 *(continued on opposite page).*

Further Results of Tests with a 600-H.P. Gas-Engine.
Trials with Engine coupled with Blowing Cylinder.
21 March 1900.

No.	Time.	Consumption of Gas per hour		Consumption of Water per hour	
		Per I.H.P.	Per Effective H.P. (French)	At Cylinder.	At Piston.
		Cub. Mètres. Cub. Feet.	Cub. Mètres. Cub. Feet.	Litres. Gals.	Litres. Gals.
			FIRST SERIES.		
1	10.17 a.m.	2·331 82·32	3·245 114·60		
2	10.44 a.m.	2·291 80·91	3·049 107·68		
3	11.13 a.m.	2·275 80·34	3·111 109·87		
4	11.41 a.m.	2·348 82·92	3·044 107·50		
5	12.16 p.m.	2·443 86·28	3·126 110·40		
Arithmetical averages		2·337 82·53	3·115 110·01	51·83 11·40	13·40 2·95
Averages from combined observations		2·345 82·82	3·113 109·94		
			SECOND SERIES.		
6	2.4 p.m.	2·318 81·86	2·725 96·24		
7	2.32 p.m.	2·345 82·82	2·823 99·70		
8	3.3 p.m.	2·304 81·37	2·890 102·06		
9	3.33 p.m.	2·369 83·66	2·915 102·95		
10	4.7 p.m.	2·335 82·46	2·917 103·02		
Arithmetical averages		2·334 82·43	2·854 100·78	40·00 8·80	10·28 2·26
Averages from combined observations		2·333 82·39	2·853 100·76		

(*concluded from page* 112) TABLE 3.—APPENDIX XIII.

Further Results of Tests with a 600-H.P. *Gas-Engine.*
Trials with Engine coupled with Blowing Cylinder.
21 March 1900.

Average Temperature of Cylinder Water.		Average Temperature of Gases.		Average Temperature of Air.	
Inlet.	Outlet.	Inlet.	Outlet.	Inlet of Blowing Cylinder.	Outlet of Blowing Cylinder.
C.° F.°	C.° F.°	C.° F.°	C.° F.°	C.° F.°	C.° F.°
	FIRST SERIES.		at Thermometer.		
7·75 45·9	36·1 97·0	8·0 46·4	499 930		
7·70 45·9	34·2 93·6	8·0 46·4	493 919		
7·60 45·7	35·3 95·5	8·1 46·6	487 909		
7·65 45·8	34·8 94·6	8·4 47·1	478 892		
7·75 45·9	37·1 98·8	8·4 47·1	486 907		
7·69 45·8	35·5 95·9	8·2 46·8	489 912	15·2 59·4	62 143·6
	SECOND SERIES.		at Pyrometer.		
8·10 46·6	40·0 104·0	9·6 49·3	555 1031		64 147·2
8·10 46·6	39·8 103·6	9·7 49·5	550 1022		64 147·2
8·15 46·7	38·3 100·9	10·1 50·2	545 1013		65 149·0
8·12 46·6	38·2 100·8	10·0 50·0	545 1013		65 149·0
8·15 46·17	38·8 101·8	10·0 50·0	540 1004		65 149·0
8·12 46·6	39·0 102·2	9·9 49·8	547 1017	17 62·6	64·7 148·5

APPENDIX XIV.

Other Large Gas-Engines (Oechelhaeuser, Otto, &c.).

The *Oechelhaeuser** engine has the distinction of being the only large gas-engine on the market working with one complete cycle per revolution, and it merits a separate description.

In its simplest form, Fig. 39, Plate 9, it has one long water-cooled cylinder in which two pistons work. The front piston is attached by its connecting-rod to a central crank placed at an angle of 180° to two other cranks on either side, which are, in their turn, connected by long side-rods to the crosshead of the back piston. This crosshead is also attached to the piston-rod of a double-acting pump which compresses the gas and air mixture on one side of its piston and air only on the other side. As the two motor pistons approach one another in the long cylinder, the explosive mixture is compressed between them and then fired electrically. The pistons are driven apart and the working stroke performed ; but before the completion of the full stroke the front piston uncovers the annular exhaust port, thus allowing the hot exhaust-gases to be discharged. The back piston, at the end of its stroke uncovers first, a port admitting cool air under slight pressure to scavenge out the remaining products of combustion, and then a second port through which the previously compressed explosive mixture from the pump is introduced. The exhaust port remains uncovered while the explosive mixture displaces the scavenging air, and then the return stroke of the pistons closes all ports, compression takes place, and the cycle is repeated.

The principal advantages of the Oechelhaeuser type of engine are as follows :—

    1. The small size of the cylinder for a given output.

    2. The rapid expansion following explosion.

    3. An impulse is obtained every revolution.

    4. The turning moment on the main shaft is produced by a couple, and the unbalanced forces transmitted to the bed-plate are much less than ordinary.

    5. The usual valves are dispensed with, as the pistons themselves act as slide valves.

The disadvantages are :—

    1. The extra complication of motor and pump.

    2. The necessity of having three connecting-rods, two crossheads and rods, and the pump gear; giving, together with the pistons, a large reciprocating mass per unit area of piston.

    3. The great length of the complete engine.

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   * Zeitschrift des Vereines deutscher Ingenieure, 1900, Band **xxxiv.**

4. The wide space between the main bearings, and the extra cost of the three cranks.

5. The possible loss of gas, owing to some of the explosive mixture blowing straight through before the exhaust port closes.

The Deutsche-Kraft Gesellschaft has constructed and put to work several Oechelhaeuser gas-engines of 600 H.P., and is now manufacturing sizes up to 1,500 H.P.

At Hörde, near Dortmund, Westphalia, two 600-H.P. sets of gas-engines, using blast-furnace gases, are employed to drive dynamos. The Hörde Bergwerk Huttenverein were among the first to experiment in the use of blast-furnace gases for motor purposes. Each 600-H.P. set really consists of two separate 300-H.P. engines, so that there is one engine direct-coupled on each side of the dynamo shaft. This arrangement means six cranks for each set, but gives two impulses per revolution. The dimensions are :—

Diameter of cylinders	.	.	.	480 mm. (18·9 inches).
Length of stroke, per piston	.	.	.	800 mm. (31·5 inches).
Speed, revolutions per minute		.	.	135
Mean effective pressure	.	.	.	66 lbs. per sq. inch.

Professor Meyer speaks highly of this type of engine, and the makers have sufficient confidence to induce them to build larger sizes. Engines with 25·6-in. and 36·8-in. cylinders are in course of construction.

The *Otto* engine up to 1,000 H.P. is built by the Gas Motoren Fabrik, Deutz; engines of this size have four cylinders of 250 H.P. each. The arrangement of 1,000 H.P. of engines coupled direct to a dynamo is shown in Fig. 40, Plate 9, the dynamo having a pair of engines, with the open ends of the cylinders facing one another, on either side of it.

Many large size engines have been constructed to run with blast-furnace gases. At Friedenshütte 1,000 H.P., in five units of 200 H.P. each, have been installed : at Oberhausen there is a 600-H.P. two-cylinder engine and two 300-H.P. engines ; and at the Düdelingen Ironworks there are two 1,000-H.P. engines and one of 500 H.P.—all these engines use blast-furnace gas. More particulars than can be given in this Appendix may be obtained from Mr. Bryan Donkin's articles on the " Utilisation of High-furnace Gases for Power." *

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* "The Engineer," November and December 1899.

List of Gas-Engine Makers.

Excluding the names of gas-engine makers who do not construct engines of 200 H.P., the following alphabetical list of the principal firms making large gas-engines may be useful :—

> Andrew and Co.
> The Campbell Gas-Engine Co.
> Charon. (Société Générale des Industries économiques.)
> Cie. Française des Moteurs à Gaz.
> Crossley Brothers.
> Deutsche Kraftgas-Gesellschaft.
> Fielding and Platt.
> Gas Motoren Fabrik.
> John Cockerill and Co. (and various licensees).
> Körting, Gebrüder.
> Letombe. (Compagnie de Fives-Lille.)
> Premier Gas-Engine Co.
> Schweizerische Maschinen Fabrik.
> Tangye.
> Westinghouse.

Discussion on 14*th December* 1900.

The PRESIDENT, Sir WILLIAM H. WHITE, K.C.B., on behalf of the Institution, thanked the Author for his valuable and interesting Paper.

Mr. HUMPHREY said there were just a few points of interest which he wished to mention. In the first place he had the pleasure of informing the members that the large meter which was used to measure the quantity of gas consumed by the engines, as tabulated in the Paper, had been checked against the fall of a gasometer specially constructed for the purpose, and had been found correct at working speeds. That relieved him of a certain amount of uneasiness which he felt, so long as he was only able to calibrate the meter at a slow speed.

In the matter of thermal efficiencies, he had throughout the Paper taken the "higher" calorific value of the gas, that was, including the latent heat of the steam. Unfortunately he did not find in the report of the Gas-Engine Research Committee of the Institution any indication of the manner in which the calorific value of the gas had been calculated, or he would have followed their method. But if the lower heating value was taken, it made a difference of fully 10 per cent. on the figure representing the thermal efficiency, and was, of course, in favour of the engine. He took that opportunity of mentioning the fact that Mr. Hugh Campbell had informed him that his firm were now making four 250 B.H.P. engines, and consequently the name of the Campbell Gas-Engine Co. was now added to the list at the end of the Paper.

Mr. Crossley, whom he was pleased to see present, would be glad to learn that, unlike the steam-engine, the efficiency of the 400-H.P. gas-engine which Mr. Crossley had supplied had gone up after six months' hard work, and he was now able to record the fact that it was 1 per cent. better in thermal efficiency, calculated on the electrical output, than it was when tried in April last.

He drew attention to Appendix V, Table 5 (page 84), with regard to the "Premier" gas-engine, which was a horizontal

(Mr. Humphrey.)

two-cylinder tandem engine, shown in Plates 2 and 3, with a positive
scavenging arrangement attached to the front cylinder, air under
pressure being blown through the clearance space of each cylinder
alternately at the end of its exhaust stroke; and thus all the burnt
products were thoroughly cleared out. The Table contained full
details, and the figures showed the remarkable result of obtaining
one I.H.P.-hour for the expenditure of 0·88 lb. of moist, bituminous,
common slack, of so poor a quality that it only contained 62 per
cent. of carbon. He had at present no means of absorbing the
whole power of the "Premier" engine; but he felt quite justified in
saying that when full load was reached a thermal efficiency of not
less than 27 per cent. would be obtained, as calculated on the B.H.P.,
and the lower calorific value of the gas.

Dr. LUDWIG MOND said he had not much to add to the
very important and instructive Paper which Mr. Humphrey had
brought before the Institution. Its great importance was no doubt
apparent to everyone, and he thought it might be said with
propriety that in the deliberations of the Institution the Paper fitly
closed the century of Steam, and fitly inaugurated the century of
Power-Gas. The Paper dealt more prominently with the
application of power-gas to the production of electricity, which
undoubtedly was at the present time the most convenient way of
transporting and distributing energy; but there were certainly also
other methods of transporting energy efficiently over great distances
and for distributing it, which were equally—and in some instances
more—economical, and which were easily adaptable to power-gas.
He reminded the members that in the United States natural gas was
transported in immense volumes over more than a hundred miles,
and distributed over very large districts. It was true the gas would
yield per cubic foot about six times the power that his producer-gas
would yield, but that only meant that either the mains would have
to be rather more than double in diameter, or that the engines
employed at certain intervals along those mains for propelling the
gas through them should be increased in number and placed at
shorter distances. Probably a medium course of increasing the

mains to some extent and decreasing the distance between the propelling engines would be adopted. The transportation of energy in the form of gas had the advantage, that the loss of energy by friction was less than the loss of energy by resistance in electrical transmission.

The author had given with his Paper a large number of elaborate Tables and diagrams, which no doubt would be highly appreciated by the members, and would prove of the greatest use to every engineer. Those Tables had involved a large number of careful and tedious experiments and measurements, which had been carried out by Mr. Humphrey regardless of trouble, and with scientific accuracy, for which it gave him great pleasure to be able to vouch. The amount of time and hard work the author must have devoted to the calculations involved, and the elaboration of these Tables and diagrams, most of the members would be able to estimate and to appreciate. The Tables showed that the production of power by means of gas-engines, and more particularly by the use of cheap producer-gas, had made fair progress since Mr. Humphrey reported, in a Paper read before the Institution of Civil Engineers on 16th March 1897, the results of his first enquiry into the subject. The principal advance made was the great increase in the size and power of the gas-engines, without which their application to large industries would have been impossible. Many gas-engine builders in various countries had attacked the problem, and had achieved success; and the Tables showed that England had not lagged behind other countries in this important movement, and that two gas-engine builders, Messrs. Crossley Brothers of Openshaw, and the Premier Gas-Engine Co. of Sandiacre, had turned out gas-engines of 400 and 500 H.P. respectively, which were running with most satisfactory results in connection with the electrolytic plant of Messrs. Brunner, Mond and Co. He could not help stating that it was a great satisfaction to him that that firm had been instrumental in promoting this important progress, and in making the participation of England in it possible, by giving the English gas-engine builders their chance of showing what they could do if called upon. The

were a little disappointed that the engine did not show at first a
higher thermal efficiency—in the Paper it was stated to be 26·2—
but he heard with very great gratification that it had gone up one
since.   He did not quite catch what Mr. Humphrey said with regard
to the "Premier" engine, as to the thermal efficiency.

Mr. HUMPHREY said it was 30·38 per cent. on the I.H.P.

Mr. CROSSLEY thought one reason why his engine did not do
better was on account of the long suction-pipes and the arrangement
for the filtration of air.   Looking at the indicator diagrams
given in the Paper, Fig. 1 (page 46), it would be seen that the
return stroke of the piston of the compression cycle did not
cross the plenum line, until the piston had come back nearly
one-fifth of its stroke.   That spoiled the record in two ways:
it showed that there was a greater fluid resistance, and it gave a
smaller card, while the friction was a constant quantity.   It might
have some little corresponding advantage in giving a higher
expansion, but he did not know that that amounted to very much.
He also thought that his engine suffered somewhat from newness; in
fact, it had been proved that it did, because the author referred to
the record of the three years' old 60-N.H.P. engine, and said that
after three years it was still improving its record.   He himself hoped
that might be the case with the 400-H.P., and that it would go on
still improving, and then perhaps the author would be able to give
records of even another one per cent.   He candidly admitted that his
firm had three reasons for keeping down the compression in their engine.
Firstly, they took into consideration the fact that the engine was
intended to run with a heavy load day and night for a long time, and
that it was absolutely important there should be no stoppages of any
kind; secondly, they took into consideration that at the time they
began to make the engine very little was known about how such
large pistons would behave under constant heavy loads; and thirdly,
they took into consideration—and he hoped his firm would be
excused for doing so—that there was an excellent supply of very
cheap gas, and that although to make a record would have been a most

(Mr. W. J. Crossley.)

delightful thing, still they thought that good, steady, plain running
was of more importance still. They did not want to hear from
Messrs. Brunner, Mond and Co., that there had been any stoppage of
any kind. With his present experience he certainly would not hesitate
to put the pressure up to a very much higher pitch with a water
piston, and should expect no difficulty whatever in reaching 30 per
cent. thermal efficiency; in fact, with a 55-H.P. engine running on

FIG. 41.   *Indicator Diagram from " ZC" Type Engine (No. 35271). Taken
during 45 minutes' trial at Messrs. Crossley's Works, 5 July 1899. Coal-gas
containing 656 B.T.U. per C. Ft. (Juncker's Calorimeter). Not including latent
heat of steam formed. Cylinder 20 inches diam. Stroke 30 inches. 160 revs. per
minute.*

Scale 120 lbs.=1 inch.

Brake H.P.	148·46
Total Gas used per hour, c. ft.	1989
Gas per hour per B.H.P., c. ft.	13·39
Units of Heat per B.H.P. .	8783·8
Thermal Efficiency per B.H.P.	29%
Mean Pressure of Diagram, lbs.	84·5
Indicated H.P.	161
Gas per hour per I.H.P. . .	12·35
Units of Heat per I.H.P. . .	8100
Thermal Efficiency per I.H.P.	31·8%

coal-gas, and indicating 150 H.P., there had already been obtained a
thermal efficiency of $31\frac{1}{2}$ per cent. per I.H.P., or 29 per cent. B.H.P.,
as shown on the indicator diagram, Fig. 41. That efficiency was
reached with gas which at the time was showing about 647 British
thermal units, something about $12\frac{1}{2}$ feet per I.HP. per hour. He
thought that was no mean record in an engine with a 20-inch
cylinder.

The author had mentioned the large size of the Westinghouse
shafts. It was very interesting to read about other people's work;

Fig. 42. Indicator Diagrams from 9 H.P. Engine (Crossley), varying from full load to light load, using coal-gas. Tube ignition.

19 June 1900.

22 June 1900.

Scale ⅟₁₈₀ᵗʰ.

(Mr. W. J. Crossley.)

but they might well be large shafts, when it was considered that
the compression, as shown in the diagram, was 140 lbs., and
that the thermal efficiency of the gas was 1,000. It might be
interesting to the members to know that his firm calculated all
their strains on a maximum pressure of 400 lbs. The gas never
exceeded 700 thermal efficiency, and the compression did not
exceed, he might say, 100 lbs., and still they reckoned to get
a pressure of 400. Putting those figures together, it might be
supposed that with a compression of 140, and a thermal efficiency of
1,000, the Westinghouse people might get perhaps 600 lbs. maximum
pressure upon their cylinder per square inch. Of course that
necessitated a very strong shaft. Then the Westinghouse Company
adopted the three-throw principle, which with four bearings required
extra stiffness to keep it nicely in line. But for all that he was very
glad to know that their thermal efficiency was only $24\frac{1}{2}$ per B.H.P.,
so that he hoped it might be taken as true that this country had
gone a little better than America for once.

With regard to fluid resistance, that was a point which he had
had in his mind for a long time, and he quite appreciated the
remarks made in the Paper with regard to the extra fluid resistance
when the engine was missing a stroke. He had given a good deal
of attention to that matter, and devised several methods for cutting
off the gas at any desired portion of the stroke absolutely, instead of
wire-drawing it; and under his system that could be done. From
the point of cut-off to the front end of the stroke the piston was
making a light vacuum, which of course assisted it to return; and
the valve being wide open during the whole time the charge was
being taken in reduced the fluid resistance to a minimum. He was
sorry to have to agree with the author that the sequence of rotation
in his firm's system of tandem engine did seem somewhat irregular,
but he was also very glad to agree with him that it made very little
difference really in the turning moment. The author had spoken
so kindly about the Crossley engine in that respect that he felt he
need not defend it, but he believed for all that that their system of
making a tandem engine was very much the best. It had a great
many advantages, an important one being that it made the pistons

very accessible. On any other system it was necessary to have either two or three cranks, or two cross-heads and two side-rods, or a gland and a piston-rod ; and all those things were open to greater objection, in his opinion, than the system which his firm had adopted. In that system if the engine was doubled and made into a four-cylinder engine, it was the best design of all. The author was less fair to his firm when he said that the system of having a stepped cam or die was not new. He should like to remind the author, however, that it was his, Mr. Crossley's, late brother's invention, brought out in 1887, and it was undoubtedly new at that time, and as far as he was aware had never been contested.

It might be interesting if he were to say that he had a Mond plant now working in his works, and doing very nicely for quite a new plant, a supply of nice clean gas being obtained from it at 147 thermal units. But he was still troubled with the old enemy—tar. He thought himself there would be no difficulty in getting rid of that. When the sawdust was clean the gas was perfectly clean, and the only thing he had to say against it was that the sawdust had to be changed too often. He had placed a piece of paper against the outlet of the gas for four or five hours, and it had only shown, with clean sawdust, a little moisture. He thought it was possible to improve the scrubbing, so as to make the sawdust last a longer time. With that plant he felt quite sure 600 H.P. could be obtained, using, as was used at present, bituminous slack ; and, with the assistance of a man to take over the job at dinner-time, one man would be able to do the work. In fact, he thought they were on the high road to success with the plant, if only they could get over the slight difficulty with the tar. He thought his firm might claim to have been the first to drive large works with water-gas. It must be well known that for nineteen years they had driven the whole of their works, which now required close on 600 H.P., with the Dowson plant, and they had scarcely ever had a hitch. Generators were not repaired once in two years, and only blown out once a year, and they had been absolutely satisfactory. The only reason which made his firm desire to change to Mond gas was the difference in the price of the fuel, which in the North was unfortunately considerable.

(Mr. W. J. Crossley.)

He had often been asked why he did not put in a central-power station, and drive the whole plant with motors. His reply was, that he was in direct competition with motor driving ; for if gas, which only cost a pound of fuel per H.P., could be brought right up to the engine without any loss through friction or anything else, and turned straight into the engine which was coupled straight on to its work, what was the use of introducing a secondary resistance in the shape of an electric drive ? He contended that to bring water-gas, whether Mond or any other, straight up to the engine, if it only cost a pound of fuel, and drive direct on to the shafting, was far and away the best system of driving works like those of his firm.

With regard to the diagram, Fig. 41, he wished to explain that he found some little uncertainty as to its indication, but Mr. James Atkinson, who took the brake-test himself, could vouch for absolute accuracy as far as it was concerned. [*See also page* 169.]

Sir FREDERICK BRAMWELL, Bart., Past-President, said the President wished him to speak of an occasion when he played the part of prophet—a very dangerous thing to do. The time of his prophecy had not yet expired, as only nineteen years out of the fifty had gone ; but on the occasion of the Jubilee meeting of the British Association at York in 1881, he said in Section G * that he thought when the next fifty years came round, the steam-engine, unless some means were found of making most important improvements— and he did not see where they were to come from—would be found only in museums. It appeared to him that it was a roundabout way of getting duty out of coal to turn the heat of the coal into steam, and get out of that steam the very small amount which was obtained, when the direct products of the coal might be used in the engine itself. He was hopeful, after hearing the Paper that evening, that he might be one of those prophets whose prophecy might come true ; at all events, everything appeared to be in favour of it. Another thing had excited an old reminiscence in his mind. He really did not know how many years ago it was—probably thirty-five—since

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* British Association Report, 1881, page 505.

Sir William Siemens attempted to get through Parliament a Bill for bringing producer-gas from the coal-pits to all places requiring to use it. Parliament, with its usual ability, determined that it was something very shocking, and the Bill was not allowed to pass. Now Dr. Mond had said that evening that that was perfectly feasible, and the proper thing to do.

Mr. ISAAC CARR said he was sure the author had placed the engineering world under great indebtedness. The author did not state the class of coal used in the producer in the course of these experiments. He himself would much like to know what coal was used, and also if any such coal as that of Lancashire or Yorkshire was equally applicable for working these producers. He asked this question because he understood that the United Alkali Co. had, at their works at Fleetwood, adopted a simple form of producer, known as the Duff Producer, fitted with an ammonia recovery plant, and with which any class of slack could be employed. Another question was, could towns' refuse be used in connection with this producer? He expected this enquiry would be followed by a smile; but he might state that this was a practice that was much in vogue. It might, too, add further to their amusement when he told them that the system was to be fitted with ammonia recovery plant. In speaking of the gas-engine makers of this country, he thought it was only fair to say, on behalf of the Stockport people, that they had erected recently at Widnes an engine of 260 H.P., fitted with all the latest improvements of water-jacketed valves, and working with coke-oven gas. Could the author give some information with reference to the tar? Nothing was said about it in the Paper, but Mr. Crossley had mentioned it (page 127). What was the amount of tar obtained per ton of coal, how was it disposed of, and what was its value? The question of gas-holders occurred to the ordinary mind in connection with this subject; and he should like to have the author's opinion upon this point, as to whether in a large installation a gas-holder would be necessary, to afford additional security for continuous working, and, if so, the capacity of the holder per unit of producer.

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Mr. J. EMERSON DOWSON said that both the Paper and Dr. Mond's remarks had been of special interest to him. The Appendices were numerous, and although he had not yet mastered all of them, he had learned a good deal from those he had been able to study. To a considerable extent the Paper dealt with the possibilities of gas-power for large central stations. There was for instance, on Plate 6, an interesting perspective view of a station with some twenty engines of 1,500 H.P. each, although the largest engine yet made did not exceed 650 H.P.; but it was no doubt useful to be prepared for what was probably coming in the near future. At the same time the author had not neglected the practical side of the question, and from that point of view he wished to make a few remarks. Mr. Carr had asked if gas-holders were necessary for central stations, and this question was one of considerable importance. In the Paper it was said that the total quantity of gas consumed at Winnington was one million cubic feet per hour, and that there was no gas-holder or storage whatever, the inference being that none was necessary. It would no doubt be an excellent thing for all concerned with gas-power, if the capital outlay and the ground space usually devoted to gas-holders could be dispensed with; but before they accepted the ruling of the author on this point the matter should be closely considered. He did not know the consumption of gas in the engines at Winnington, but assuming for the moment that there was an aggregate of 1,000 H.P., it would be found that the engines consumed only about one-twelfth of the total volume of gas produced, while eleven-twelfths were consumed for heating furnaces. Moreover the mains to convey that great volume of gas must necessarily be large. It was well known that in gas-engines of the " Otto " type, such as were used at Winnington, the gas suction was considerable, and with the full load on there were usually from 70 to 80 suctions per minute for each cylinder. These suctions caused great fluctuations in the pressure of the gas in the main, and even with a main of ample size, and with a gas-holder working freely, the fluctuations were seldom less than 6 inches, and were often equal to 12 inches in the main. He had himself seen fairly large gas-holders at a considerable distance from the engines rise and fall

with each suction. Where there were two or more engines drawing from the same main the case was rather worse, and when the engines happened to synchronise he had seen the gas-bags drawn almost flat, although the holder pressure was equal to about $1\frac{1}{2}$ inches of water. He concluded therefore that it would not be safe to work large engines without a gas-holder or other means for checking the great fluctuations in pressure caused by the suction of the pistons. It might be asked why then was no gas-holder wanted at Winnington? He thought the probable explanation was that the mains at that place contained a large volume of gas, while the proportion of gas consumed by the engines was relatively small.

Dr. MOND said Mr. Dowson was quite correct.

Mr. DOWSON said that at a central station there would be many engines drawing gas, and he could not help thinking that engineers were not yet in a position to say that a gas-holder could be dispensed with. It was well known that for furnace work no gas-holder was wanted, as the flow of gas was continuous and the fluctuations in pressure were hardly appreciable. For example, at the works of Messrs. John Brown and Co. in Sheffield, in connection with their armour-plate work, he had several producers working with ordinary bituminous coal, and there was something like half a million cubic feet of gas consumed per hour. All the gas was led from the different producers into one flue, and flowed on to the furnaces: there was no gas-holder, but then there were no engines. With regard to Dr. Mond's plant for recovering ammonium sulphate, in combination with the production of a useful gas, the idea was an excellent one, as everybody must acknowledge who understood such matters technically; but looking at the results critically they were faced with the fact that the gas contained 16 per cent. of carbonic acid—in other words, that something like 55 per cent. of the carbon in the fuel remained as carbonic acid in the finished gas. This large percentage of carbonic acid was doubtless compensated for to a certain extent by the high percentage of hydrogen—29 per cent.— but it certainly looked as though some improvement were desirable.

(Mr. J. Emerson Dowson.)

In the gas made in his own plant, the hydrogen was not as high as in the Mond gas : it usually contained about 20 per cent. of hydrogen, and the carbonic acid was from 4 to 6 per cent. He confessed however that even this comparatively small percentage of carbonic acid was a source of regret, and he had often tried to find means of reducing it. In the Mond plant the recovery of ammonium sulphate was a good set-off against the high percentage of carbonic acid, but in the Paper it was suggested that the Mond plant might be worked without the recovery process. No doubt if the recovery were given up less steam would be formed, and there would probably be less carbonic acid ; but then there would be less hydrogen also, and on this basis he could not imagine that the efficiency of the plant would be a high one. Estimates were put forward in the Paper of the cost of power derived from current produced at a central power station compared with the cost of current produced at the mill or factory where the power was to be used. In the first case the cost per H.P. was given at the switchboard, but as the current must be sent from the central station to the factory, the estimate should include the cost of distribution and its attendant losses. No doubt it was difficult to estimate these items of cost, but the owners of the central station would have to cover *all* outgoings, and as the station would not be run as a philanthropic institution, they must also include a reasonable profit on their capital outlay and working cost. The factory owner would necessarily want to know what the central power station would charge for the current delivered at his factory, so that he might compare this with the cost of current produced at the factory itself. It was a similar case to that of the gas companies : it would not be sufficient for consumers to know the cost of the gas in a gas-holder at the gasworks. They should know what it would be in their houses. His own view was that instead of the mill-owner or user of large power deriving his power from current from a distant station, it would be better and cheaper for him to use gas-power instead of steam-power at his mill, or to produce the current at his own mill or works when he desired to drive electrically. It appeared to him that the central station was better suited for the

supply of current for electric lighting and for comparatively small users of power. As was well known, he had long advocated gas-power for central stations, but he had had to play a waiting game. It was comparatively easy to produce any quantity of gas required, but for a large production of current fairly large units of power were necessary, and it was only within the last two years that a gas-engine of more than 300 H.P. was built. They were now made up to 650, and still larger ones were being made. There was therefore a good prospect of an early development in the use of gas for large powers. In conclusion, he expressed his thanks to Dr. Mond and to those who had been associated with him in giving such a useful impetus to the subject of gas-power. [*See also page* 205.]

Mr. A. ROLLASON said that a Mond plant of 1,000-I.H.P. capacity had been erected at the works of the Premier Gas-Engine Co., Sandiacre, near Nottingham, and was started to work in February 1900. It had been in daily use making gas for the engines driving the works, testing engines, and in the foundry heating the core stoves and drying moulds. The plant was constructed without ammonia recovery, but with steam-recovery towers, and a portion of the exhaust gases from one of the engines was returned to the producer, the exhaust pipe from the engine being connected to the air inlet to blower. The fuel used was the common Nottingham slack, costing at the present time 10s. per ton delivered to the works. No extra water was required, except that used for feeding the boiler which was used to raise steam for driving a small engine of 8 H.P.; the engine drove the blower, pump, and dashers in the washer. The exhaust-steam entered the air supply after leaving the air-heating tower, and before passing to the regenerator. This plant was tested by himself for a period of three weeks, and the quantity of gas made varied from one-third to the full capacity of the plant; the gases made at any load between this range were practically constant both in quality and quantity per pound of fuel fed to the producer. At full load 1 lb. of fuel fed to the producer gave $72 \cdot 25$ cubic feet of gas at 15° C., resulting upon analysis of the following composition :—

(Mr. A. Rollason.)

$$\left.\begin{array}{rr} H & 24 \cdot 00 \\ CO & 16 \cdot 00 \\ CH_4 & 2 \cdot 20 \end{array}\right\} \begin{array}{l} 145 \cdot 9 \text{ B. T. Units per cubic} \\ \quad \text{foot of gas at } 15^\circ \text{ C.} \end{array}$$

$$\begin{array}{rr} O & 0 \cdot 00 \\ CO_2 & 12 \cdot 40 \\ N & 45 \cdot 40 \\ \hline & 100 \cdot 00 \end{array}$$

At one-third load, 1 lb. of fuel fed to the producer gave 70·85 cubic feet of gas at 15° C., having the following composition :—

$$\left.\begin{array}{rr} H & 21 \cdot 60 \\ CO & 16 \cdot 40 \\ CH_4 & 2 \cdot 40 \end{array}\right\} \begin{array}{l} 144 \cdot 5 \text{ B. T. Units per cubic} \\ \quad \text{foot of gas at } 15^\circ \text{ C.} \end{array}$$

$$\begin{array}{rr} O & 0 \cdot 00 \\ CO_2 & 12 \cdot 40 \\ N & 47 \cdot 20 \\ \hline & 100 \cdot 00 \end{array}$$

The producer after standing fourteen hours required 220 lbs. of fuel to fill up, equal to 22 lbs. per hour working. At the low load the fuel fed to the producer was 299 lbs. per hour, and to the boiler 65 lbs., or a total consumption of 386 lbs. per hour, and the gas made per lb. of the total fuel used was 54·9 cubic feet at 15° C.

At a higher load the fuel fed to the producer was 636 lbs. per hour, to the boiler 65 lbs., proportion of stand-by losses 22 lbs., total fuel used 723 lbs. ; the gas made per lb. of the total fuel used for all purposes was 63·55 cubic feet at 15° C. In ordinary daily working at fair loads a good gas-engine would give one I.H.P. per hour on 1 lb. of common slack used for all purposes in a small Mond plant.

The slack used was tested in a Bomb calorimeter, and gave 12,200 thermal units per lb. ; 1 lb. of this slack fed to the producer made 72·25 cubic feet of gas at 15° C., having a heat value of 145·9 thermal units per cubic foot. The gas made from the 1 lb. of slack contained 10,451 thermal units out of the 12,200 in the slack, the producer having an efficiency of 86·4 per cent. ; this high efficiency resulted from the use of the steam-recovery towers, and by returning part of the exhaust products to the producer.

The same quality of slack was used in the boiler, and the quantity burned was greater than would be in one constructed to burn small slack or arranged for gas-firing. During the ten months the plant had been at work no repairs had been required, and it had worked without a hitch or any trouble whatever. One man attended to the plant, and in daily work the time required from the starting of the blower forcing air to the producer to the time the gas-engines were working was only $1\frac{1}{2}$ minutes; at the week end the time required was only 3 minutes, and when shut down for eight days under 5 minutes. There had been no time lost or fuel wasted blowing up during the time the plant had been at work.

Discussion on 18th January 1901.

The PRESIDENT, Mr. WILLIAM H. MAW, stated that, as such a large number of communications had been received from members who desired to speak on the subject, it would be quite impossible to complete the discussion that evening. While it was very desirable that so important a subject should be thoroughly discussed, it was also desirable not to interfere with the arrangements already made for the regular meeting in February. The Council, therefore, proposed that if the discussion was not finished that evening a special meeting should be held that day three weeks, to continue the discussion, and to hear Mr. Humphrey's reply.

Professor F. W. BURSTALL first expressed his admiration for the way the author had carried out the extremely difficult work of experimenting on large gas-engines. No one who had not had the experience of making a test on an engine of 100 to 200 H.P. knew the difficulties that were to be encountered with a gas-engine as compared with a steam-engine; and he personally felt very much gratified that the author had been able to furnish such data with regard to large engines, data which he was perfectly certain did not

(Professor F. W. Burstall.)

exist anywhere else. The first matter about which he wished to say
a word or two was the method of governing. The author, and he
believed many gas-engine makers, were of opinion that governing
by throttling was not possible with engines using a weak gas. That,
he thought, was due to the method of ignition which was usual in this
country. With the hot tube ignition, when working with a weak
charge and a low compression, it was extremely difficult to ignite the
gas, and if electric ignition was used it must be used with a spark of
very large dimensions. The trouble that was met with in governing
by reducing both air and gas was almost entirely due to that difficulty.
If an attempt was made to ignite with the ordinary tube, as the load
came down the engine missed fire. Even with electric ignition a
result was obtained as shown in Fig. 43.

FIG. 43.

FIG. 44.

The diagram corresponded with ignition at the same point of the
stroke when weakening the charge. Everyone knew that such
diagrams were inadmissible for correct working, and the only plan
was to alter the lead of the igniting spark. He might say, without
in any way forestalling his own Report,* that it was necessary in
certain cases to make the spark pass as much as 0·7 of the stroke
in order to get a correct ignition of the charge; and he imagined
that the failure to ignite when governing by throttling with weak gas
was almost entirely due to the defects in ignition, of course taking
into account the number of thermal units which were present in a
cubic foot of the mixture. It was quite immaterial for ignition

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* The forthcoming Second Report of the Gas-Engine Research Committee.

purposes whether the ratio was 3 to 1 on a weak or 10 to 1 on a rich gas. There was one other point on which he should like to say something, namely with regard to the change of economy when the gas charge was cut down. The changes he was alluding to were those purely on the indicated power. The brake power was most important from a commercial point of view, but from a research point of view it was a matter depending entirely on the engine which was employed. If the richest possible charge which an engine would burn was started with, and the amount of gas cut down, there would be found a steady rise in the economy until a certain point was reached.

Fig. 44 showed roughly an average indicator diagram, with one curve lying above it, and one curve lying below. The curve which lay below was a curve plotted on the ordinary assumption of constant specific heat, that was, it was a curve which said that the gas was expanding without heat being either added or thrown out. The curve plotted above was plotted on the assumption of a variable specific heat, and which also was a curve in which heat was neither gained nor lost. The lower curve apparently showed that the charge was gaining heat, and was of course the expression of after-burning, or slow combustion, which led to the numerous disputes of 10 or 12 years ago, as to exactly what happened. The curve above showed that the charge was losing heat throughout the whole stage of its expansion. The combustion was probably entirely finished at the point of maximum pressure. That, he thought, bore out Dr. Slaby's original idea, that combustion was completed at the point of maximum temperature. There were, however, cases where actual after-burning could be obtained, that was to say, a gas-engine could be made to work in such a manner that the expansion line would always come just above the adiabatic drawn from the point of maximum temperature, the charge being extremely weak, and the burning slow. According to the theory of thermal dynamics, such a case should yield inferior economy, because the heat was not added at the maximum temperature. He was intensely gratified when applying the test to his own work to find that the very weak charges were not so efficient as some of the richer charges. It was always a

(Professor F. W. Burstall.)

gratification when one found theoretical results truly borne out by experiments; and he expressed his thanks to the author for his excellent results.

Mr. WALTER DIXON said he thought the tabulations in the Paper were the result of much careful and laborious work. The author was to be congratulated on having been able to bring forward a subject which in its entirety was only possible at the present day, and was entirely new, namely, the combination, as a practical matter, of power-gas with *large* gas-engines. His own association with the matter was somewhat interesting, inasmuch as he was connected— so far as the electrical work was concerned—with what he believed were absolutely the first experiments in this class of work, namely, those which Mr. Thwaite carried out at Wishaw * a few years ago. Those experiments were on identical lines with those referred to in the Paper at present under discussion, inasmuch as producer-gases, from which the by-products had first been recovered, were used directly in gas-engines: the only difference being that in this instance the gas-producer was a blast-furnace for the production of pig-iron, and the gas-engine was a *small* one. The result was successful and opened out immense possibilities; but progress was practically impossible, inasmuch as at that time, and in fact until within the last year or two, gas-engines of over 100 H.P. could not be obtained, nor could makers at that time be induced to experiment upon engines of larger power. Such a plant as Mr. Humphrey had described in his Paper, consisting of gas-producers with recovery-plant and gas-engines, was planned out and would have been erected five years ago in one of the Colonies, had it been possible to obtain engines of suitable size. Simultaneously with the erection of the Wishaw plant, experiments were being carried on at different works on the Continent; and whether it was significant of their national caution, wisdom, or energy, it stood to the credit of their Continental friends that they were about two years ahead, and had the

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* Transactions, West of Scotland Iron and Steel Institute, December 1896, page 49.

priority in the publication of the results of experiments with large
power gas-engines.*   From this it was obvious that the progress
which the author had been able to report must be ascribed to
the possibility of obtaining *large* gas-engines.   There were several
systems of producing gas for use in engines; he believed that
the largest gas-producer and recovery-plants now in Britain were
not on the Mond system, and they were able to satisfactorily deal
with a caking class of coal and even towns' refuse, which he
understood was not possible with the Mond producer.   As to the
by-products, he had seen records of actual results which, so far as
sulphate of ammonia was concerned, were better than any of those
mentioned by the author.

There were one or two points which in his opinion called for a
word of comment.   In Appendices X and XI (pages 95–97) the
author had given some data dealing with various load factors, with a
view to showing how much better his system would be when applied
to electric central stations.   The lowest he had figured upon was a
load factor of 33 per cent.   He (the speaker) had gone through a
recent issue of " *Lightning*," and taking the first page which dealt
with 40 or 41 stations, he found that the maximum power used at
any one time was only about 70 per cent. of the total installation,
while the load factor was only 10 per cent. of the maximum load, or
7 per cent. of the total load, this 7 per cent. comparing with the
recorded experiment of 33, 50 or 100 per cent. taken by the author
of the Paper.   He thought in that way one did not obtain exactly a
fair comparison.   Another point was that in Appendix X (page 96)
the cost of fuel was put down for 83 stations at $0 \cdot 778d$. per unit.
Taking from the same publication Liverpool and Manchester—the
cities which perhaps were nearest in their coal arrangements to the
site of the author's experiments—the load factor compared with the
full power of the stations was only about 11 per cent., and the cost
of fuel did not come out to $0 \cdot 778d$. but only to $0 \cdot 4d$. per unit.   The

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* He had seen most of the engines referred to by the author, both on
the Continent and in America, and it was perhaps a significant fact that most of
those engines were intended for use with blast-furnace gas.

(Mr. Walter Dixon.)

diversity of conditions under which the author's experiments had been carried out as compared with central station work, in which steam had to be kept up all the year round, must not be lost sight of. On a certain day in London two weeks ago it was comparatively clear at one o'clock, but between two and three o'clock there was a dense fog, which meant that full power in every central station had to be got up in the boiler-house for that brief time. With such conditions—which were more or less universal—the author's experiments could not be expected to compare favourably.

The question of the parallel running of generators had been referred to, and the author believed the difficulties could fairly be got over, though for his own part he did not think such a system as was mentioned in the Paper of running continuous-current machines for driving alternators would be tolerated or even necessary. Scotland, which was not always the first country to try experiments, had the courage of its convictions a few years ago, and he believed was the first to put down central station gas-engines and alternators. As to the results it is perhaps only necessary to say that neither the gas-engines nor the alternators were there at present. Matters however had advanced since then, and while both at Hörde and other places difficulties had been experienced, he understood from friends on the Continent that the difficulties had been got over; and the fact that extensions of existing plants were in progress confirmed this.

In conclusion, he stated that in his opinion the main point which this Paper should impress upon everybody was, that it was now within the range of possibility to generate power in large or small units by means of gas-engines and producer-gas with an expenditure of only one to two lbs. of common coal or slack; and that the whole value of the fuel could practically be recouped from by-products. He thought the world, apart from Great Britain, appeared to be availing themselves of this fact. There seemed little doubt that at the present time there were on the Continent and in America engines actually on order or constructed amounting to something like 100,000 H.P., and of this, as far as he was aware, about 2 per cent. was destined for our own country.

Mr. DUGALD CLERK congratulated the author upon his able and laborious Paper. He did so more sincerely because he had some little critical remarks to make. In making those remarks, it must not be understood that he depreciated in any way the important work that Dr. Mond and Mr. Humphrey were engaged in. He agreed that the work was exceedingly important and he took the view he had long taken, the view which Dr. Mond had now adopted, that the gas-engine would be the engine of the 20th century. In the last twenty-six years the gas-engine had sprung up from nothing. When he first had to do with gas-engines twenty-four years ago, the largest gas-engine in Britain was a little atmospheric engine made by Messrs. Crossley, in which the piston was shot up a cylinder and where the maximum power possible was 3 H.P. That was supposed to be a huge engine in 1876. The " Otto " engine, the compression-engine which was a great advance in gas-engines in this country, came into use in 1878. Gradually the size of the engine increased until at the Kilburn Show in 1879, where he was exhibiting his first compression-engine, the largest gas-engine was a monster of 16 H.P. It was known in those days as the king of gas-engines, and it was supposed to be a very huge affair, and was a huge affair at that time for a gas-engine. After that the gas-engine went on steadily increasing in power, until the difficulties which were due to increased dimensions began to be more apparent to constructors. But before he said anything of the difficulties of large power-engines, he wished to consider first the work that Dr. Mond had associated himself with in conjunction with his colleague, Mr. Humphrey, namely, the Mond gas-producer. He quite agreed with the last speaker that other gas-producers existed, and that producer-gas, even water-gas, was no new thing in this conntry; but what he wanted to consider was the nature of the advance which Dr. Mond claimed to have made, and what was the nature of the real advance which he had made. He agreed with Dr. Mond and the author in some respects, but disagreed in others. Dr. Mond had attacked a very difficult problem, which was to make a gas-producer which would produce good gas, and at the same time recover the ammonia completely if possible from the gas so produced. That was a very difficult problem, because the

(Mr. Dugald Clerk.)

conditions which were proper to the production of good gas were to
a very great extent antagonistic to the production of ammonia.   To
produce good gas, the best thing to do with a producer was to work
at a much higher temperature than the temperature at which Dr.
Mond was working.   One of the interesting points in the Mond
producer was the very low temperature at which the carbonization
was conducted.   The author had been good enough to show him
over the works during the last week, and he had had the pleasure of
inspecting the producers and the two gas-engines which were driven
by them.   To recover the nitrogen of the fuel, it was necessary to
take care that the temperature of the ammonia evolved and the
decomposition of the coal were not high enough to decompose the
ammonia, and to turn it into nitrogen and hydrogen again.   Therefore
it was important to keep down the temperature of the producer.   To
do that, Dr. Mond very ingeniously flooded his producer with an
excess of steam, something like two-and-a-half times greater than
the weight of fuel gasified.   The consequence was that Dr. Mond
had to make arrangements to recover a portion of that heat, or his
producer would be very uneconomical.   In addition to the air which
was passed through an ordinary producer, such as the Dowson
producer, together with a little steam to decompose and produce
hydrogen, Dr. Mond had to pass enough steam to keep his
temperatures within the required limits, and to wash or carry away
the ammonia produced without decomposition.   He did that in a very
ingenious and able way, and he succeeded to a very large extent in
getting good gas and with a great deal of ammonia.   He, the
speaker, had gone into the figures carefully and considered that Dr.
Mond had not succeeded in getting what he should call a high
efficiency in the producer.   In one respect the author's figures
were a little confusing.   He had been exceedingly careful and
accurate, but the way he put his figures was a little misleading
to anyone reading the Paper even with care.   It was stated that the
calorific value of total gas made as a percentage on the calorific value
of the total fuel gasified was 84·1 per cent.   That conveyed to a
person reading the Paper for the first time the idea that the
author was claiming for the producer an efficiency as a producer

of 84·1 per cent. On careful perusal of the Paper that appeared
not to be só. The 84·1 per cent. was the author's estimate of the
proportion of heat obtained on burning gas produced, compared
with the total heat evolved after the fuel consumed in the producer
was burnt directly. In a Paper Mr. Humphrey read before the
Institution of Civil Engineers in 1897,* it was stated that for every
ton of fuel gasified in the producer about a quarter of a ton or a
little less of added fuel was required to produce the steam necessary
to add to the producer. The consequence was that the real efficiency
of the particular mechanism was the proportion of the heat produced
on burning the gas to the total fuel gasified in the producer, plus fuel
used to produce the necessary steam for operating the producer; and
that brought down the efficiency to something like 67 per cent.,
which made it below the efficiencies of other producers which did not
attempt to recover the ammonia. Apart, however, from the question
of efficiency, he believed the author made the suggestion that the
exhaust-gases of the gas-engines would give heat enough to produce
that steam without added fuel. That might be so, but that was not a
proper figure to take in dealing with the efficiencies of the producer,
because other things could be done with the exhaust heat and with the
water-jacket heat from the gas-engine. Therefore on the author's
own figures the real efficiency of the Mond producer was not more
than about 67 per cent. instead of 84 per cent. Then again he was
very much puzzled on reading the Paper to know how the author had
determined the volume of gas produced by the producer, and still
more puzzled when he got to the works to find that the producers,
twelve in number, in three sets, were capable of converting 240 tons
of coal a day into gas. When he was there, they were really converting
200 tons of coal a day into gas, and the greater part of that gas was
used for heating steel and other furnaces, and the gas-engines were
only taking a small quantity by a sort of by-pass, scrubbing it with
sawdust and conducting it to the gas-engine. The author had
been kind enough to inform him of the method he adopted to

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* Proceedings, Institution of Civil Engineers, 1896–97, vol. cxxix. page 190.

(Mr. Dugald Clerk.)

determine the volume of gas coming from the producer, and told him that it depended upon the estimate of the carbon lost by collecting all scrapings in flues, tar, etc., making an allowance for the loss of carbon, and assuming that the difference between the carbon put in and the carbon so lost had appeared in the gas. In the circumstances he did not think for a moment that the author could have done any better, because he was in great difficulties; but before one could come to any very accurate conclusions, such conclusions, for instance, as justified anyone speaking of a very large central station using gas with certain percentages of economy, there should be installed on the Mond system a moderate-sized station, say giving 2,000 H.P., where all the gas went into the engines. In many tests which he had conducted on other gas-producers, it had been always his practice to weigh out all the fuel and to make sure that that fuel was burnt in the producer, even to damp down the producer and take out the fuel that remained, and weigh it after cooling and drying, in order to find out exactly what had gone into the gas, or to measure it off through a large gasometer; but of course that could not be done with producers operating on so huge a scale. His view was that, in the producer the author had mentioned, he had in some way failed to trace all his carbon. His reason for saying that was based on a rather careful study of the different analyses of the Mond gas given in a Paper read by Mr. Humphrey at the Institution of Civil Engineers and in the present Paper. In those analyses certain amounts of oxygen from the nitrogen of the air were disposed of in certain ways. In the Paper the 42 per cent. of nitrogen mentioned meant that a little over 10 per cent. of oxygen (10 volumes of oxygen) was carried in with the 42 per cent. of nitrogen—assuming that there was no oxygen lost —and that that oxygen was divided between the carbonic acid and carbonic oxide, and that a certain amount of hydrogen was made; he had calculated how much water had decomposed, and so far as he could discover from the analyses, assuming their correctness, a very large part of the volatile matter of the coal—that was the original coal put in—had disappeared. He felt that the author had done everything with every possible care, and had been perfectly frank

about everything; but to establish figures of that kind that were really world-wide figures, figures which would be taken all over the world as correct, other experiments should be made. His impression from the analyses was that the real efficiency of coal gasified in the producer did not amount to much over 50 per cent. The method of cooling caused considerable losses, and the united efficiency of gasifying and heating could not therefore be very much over 50 per cent.

Mr. HUMPHREY mentioned that the gas has been measured in the Sandiacre Works, and it had come out rather higher than the calculated figures.

Mr. CLERK said he was very glad to hear that, as it settled the objections so far as the small plant was concerned. He asked if he might take it that the real efficiency was 84 per cent.

Mr. HUMPHREY said that probably Mr. Clerk's calculation would be correct with regard to the 67 per cent., when calculated in the manner Mr. Clerk had described; but he himself would have some remarks to make on this point later (page 195).

Mr. CLERK said that his impression was that the efficiency would be lower, but he was glad to know it was really about 67 per cent. He had great pleasure in seeing the two engines at work, the Crossley engine and the "Premier." They were both working exceedingly well, and in fact he had never seen large power-engines work so well. Large power gas-engines had given great trouble in past years, and it had been his sad fate to assist in considering the causes of break-down in many engines of over 100 H.P. Although, therefore, those two engines worked very well, it must not by any means be supposed that the makers were yet in a position, either on the Continent or in England, to execute large orders for big gas-engines. Although both engines he had seen were not exactly experimental, they had emerged too recently from that condition for one to have much confidence in going ahead. For instance, in

(Mr. Dugald Clerk.)

the Crossley engine, the pistons were not water-jacketed. The great
difficulty in large gas-engines was to prevent pre-ignition. In all
gas-engines an inflammable mixture was taken in on the forward
stroke, the mixture was compressed, and ignited at the proper time.
If, however, the engine was above a certain size, the heat was
conducted away from many of the parts too slowly, and the
consequence was that those parts became practically red-hot. With
a 100-H.P. engine at full work, by going into the dark and watching
the end of the piston from the outside, it would be found that when
the full load was on the engine the bottom of the piston was at a red
heat. The consequence of that was, that gas-engine makers had had
to adjust their machines to prevent pre-ignition. If the temperature
and compression were kept sufficiently low, pre-ignition would not
take place, but if it rose above a certain point the ignition would
come with great frequency and force on the back stroke, and pull up
the engine in time. Messrs. Crossley, in settling the compression
of the large engine at 60 lbs. acted very prudently, and with full
knowledge of what was before them. They knew quite well that,
without a water-jacketed piston, if they compressed higher in a large
engine at that speed they would probably have pre-ignition, and pull
up the engine. The engine had been beautifully adjusted by
Messrs. Crossley, with all their knowledge and skill, and just ran
perfectly : a little bit more, and there would be pre-ignition.
Notwithstanding that, Messrs. Crossley were very prudent, and did
very rightly in not increasing the compression. In his view they
also did rightly in avoiding the use of water-jacketed pistons in the
first large engine they built. To run a large engine with high
compression without pre-ignition, it was necessary to have a water-
jacketed piston, and he had no doubt that now the difficulties of
those pistons would be overcome. In an engine running without a
water-jacket the end of the piston had to be allowed a full $\frac{1}{8}$-inch
clearance, with something like a 30-inch cylinder, and it depended
absolutely on the rings for keeping gas-tight in starting the
engine. If that was not done, the end of the piston expanded so
much, that after the full load came on he had often found an engine
giving 100 H.P. pull up quite easily. In some cases, if the heating

was too rapid there might be a smash. By reducing the piston in that way any chance of such a catastrophe was prevented, but with a water-jacketed piston the piston could be kept a good fit from the beginning, so that it remained quite tight. But assuming for a moment that the water circulation stopped, then there would be a big smash, and the whole cylinder torn up, or the connecting-rod bolts pulled out. There had been smashes of that kind from other causes, where gas-engine pistons had seized. He believed that with care a water-jacketed piston would succeed, although there were very few at work yet. He had as much interest as anyone in desiring to see the advance of the gas-engine. It was a subject to which he had now devoted twenty-six years of his life, and he should be delighted to see large gas-engines come into use at once. But he thought the interest of large gas-engines would be better served by moving a little slowly—not too slowly—and by not being discouraged by seeing large gas-engines used on the Continent, because there they had very great difficulties too.

Mr. JAMES ATKINSON said that having had something to do with the designing of the Crossley engine shown in Plate 1, he should like to make one or two remarks. When it was started it was the most powerful and successful gas-engine in England. Previous attempts at large engines had been made, but had not been successful. It was designed in accordance with a very strict specification as regards power and regularity of turning moment, and was found to comply with those requirements. Personally he felt very proud of having anything to do with it. He was much obliged to the author for having shown so clearly that its regularity of turning moment was such that its fly-wheel only deviated from absolute regularity by 0·38, or one-third of one degree when running on its intended load. That regularity was largely due to two things. In the first place the engine governed on a hair-line between two steps of a die on the gas-valve, and in the second place in consequence of the large amount of energy stored in the fly-wheel. The construction of the fly-wheel was shown in Fig. 8, Plate 1. It was the invention of Mr. Crossley, and he believed was the first instance in which the full strength of the

(Mr. James Atkinson.)

fly-wheel rim was maintained whilst keeping a smooth external surface. Fly-wheels in gas-engines to have very great regularity contained a large amount of inertia, and to keep them as light as possible it was necessary that the periphery of the wheels should run as fast as possible. As engines increased in size the revolutions decreased, allowing the diameters of the wheels to be increased beyond sizes which would go in one piece by railway, hence the necessity of making them in pieces; this construction combined with the governing was responsible for the remarkable regularity shown in the Paper. It was interesting also in that direction to notice that the irregularity of the Crossley engine was 0·83 per cent., and in the Paper it worked out in the "Premier" engine at 1·35, in spite of the better cycle of the explosion to which the author referred. As a matter of fact the cycle of the cylinders was not so important as most people imagined. At the last meeting his attention was forcibly drawn to Appendix V, Tables 1 and 5 (pages 81 and 86), giving a comparison between the diagram taken from the Crossley engine and that taken from the "Premier" engine. He saw that the "Premier" engine gave a thermal efficiency of 30·38 per cent. per I.H.P., and 22·87 per cent. per B.H.P. The corresponding figures of the Crossley engine were 26·23 and 21·78 per cent. respectively. He understood from the author that the Crossley engine had since improved 1 per cent., bringing up its thermal efficiency to 22·78 per cent. Looking at the superimposed diagrams, Fig. 30 (page 65), it would be seen that the maximum pressure of the "Premier" engine was now 330, and the maximum pressure of the Crossley engine was only 250. It was useful also to consider that in the Crossley engine the chief moving parts consisted of one crank-shaft, two connecting-rods, and two light ordinary pistons. The "Premier" engine, on the contrary, had a crank-shaft, one connecting-rod, two gas-engine pistons, a large scavenging piston, two side rods, a heavy crosshead, and crosshead guides. The result of the friction of those extra parts, together with the increased resistance, was clearly shown in the difference of the mechanical efficiency of the two engines. The mechanical efficiency

of the Crossley engine came out at 83 per cent., showing more friction than there really ought to be. It might be that the engine was not run really in its best condition, and it would probably improve very much, because his experience with all their larger gas-engines was, that the mechanical efficiency exceeded 90 per cent. He had not the slightest doubt that that engine would eventually give a mechanical efficiency of over 90 per cent. With the greater number of parts of the "Premier" engine compared with those of the Crossley engine, it would be found that the mechanical efficiency of the Crossley engine would be always much higher than was possible with the "Premier" type of engine. If a business man bought power, he wanted the most power he could get out of his fuel; he wanted the highest B.H.P. he could get for a certain quantity of fuel, and for that purpose it was necessary to have as simple an engine as possible. A much higher efficiency could have been obtained from the engine if the compression had been put up, but it was made to do a certain duty, which it had done, and being the first, care was taken to be on the right side.

<p style="text-align:center">Discussion on 8th February 1901.</p>

Mr. BRYAN DONKIN, Vice-President, wished in the first place to add his appreciation of Mr. Humphrey's excellent Paper. It was full of facts and figures, and had fortunately a minimum of opinions and much original matter. The subject of the production of cheap power-gas and its utilisation was most important. To obtain the cheapest power with the lowest grades of coal with or without a recovery plant, especially in the present day with the great developments of electrical energy, for power and light, was of the first importance. Referring to the 400-H.P. Crossley two-cylinder gas-engine test, every care seemed to have been taken to make a first-class experiment, and indicator diagrams were given. The study and plotted results of forces and turning movements with the speed

(Mr. Bryan Donkin.)

variations during a cycle of two revolutions were very interesting. The degree of compression in the test was rather disappointing, as it was only five atmospheres. He would have liked to see it about eight atmospheres, higher compressions now being very usual, and particularly as the maximum explosive-pressure was about sixteen atmospheres. The author in giving particulars of a 650-H.P. gas-engine described it as one of the largest two-cylinder engines in existence. He presumed the author meant in England, as there were many gas-engines of 1,000 or 1,500 H.P. working on the Continent.

The Mond producer seemed an excellent one, and was the first he believed to produce cheap gas from bituminous or slack coal. Coke or anthracite had been chiefly used hitherto, and in most localities the cost per ton was at least double or treble the price of the small coal used in the Mond producers. That was an important difference. He thought the Mond producer might be classed as one of the temperance type, considering the enormous capacity and quantity of steam or water which went into the interior of the apparatus—about $2\frac{1}{2}$ tons for every ton of coal—for conversion into hydrogen, and to keep the temperature down.

Referring to the Tables in the Paper, he had made a small collection of modern gas-engine tests (pages 154-161) which he thought might be of interest, giving a selection, not only of twelve gas-engine experiments with power or generator gas of a heating volume of only 150 thermal units per cubic foot, but also six tests with gas-engines with natural gas in the United States. This gas had a heating value of about 1,000 thermal units per cubic foot, or about six times the heating value of producer-gas. The tests were arranged in order of merit of thermal efficiency per B.H.P., and for powers from 60 to 600 B.H.P. The maximum heat efficiency of the two very different gases came out about the same, namely, about $25\frac{1}{2}$ per cent. per B.H.P.

Referring to the modern tendency of gas-engines, their leading features seemed to be somewhat on the following lines:—greater compression, better-shaped clearance spaces, water-cooled pistons for large powers, positive air-scavenging by means of a special air-pump

or other arrangement, and electric ignition. This ignition was largely used on the Continent, while in England makers seemed to keep more to the tube ignition. Double-acting engines were again coming in, as would be seen by the one lately made by Messrs. Körting, of Hanover. The piston speed of large gas-engines seemed also to be on the increase. Taking, for example, a 1,000-H.P. gas-motor, this was about 1,000 feet per minute, which was the same or perhaps a little higher than that attained in modern steam-engines. Referring to Fig. 28 (page 63), giving the cubic feet of gas plotted for the 400-H.P. Crossley gas-engine, if the zero of the I.H.P. were taken, one ought to have the zero of the cubic feet of gas : but the curves did not seem to quite justify that conclusion ; perhaps the author would kindly explain it.

With regard to producer-gas, he quite agreed with the author that practically little or none of the gas was lost in even miles of pipes, whereas it was well known that with steam a few yards produced considerable condensation. It was stated that Mond gas was being sold at 2d. per 1,000 cubic feet with large plants. That of course, was a remarkably low figure, and, he supposed, included some profit. For the smaller plants spoken of, say 250 H.P., he presumed the price per 1,000 cubic feet would be a good deal more. The heat efficiency of the producer—an important point—given as 80 per cent. and more, seemed very high, but it was not quite clear whether the coal used to produce the large quantity of steam required had been included. That point, he thought, had been alluded to by other speakers. He would also like to ask the author whether there was any smell or smoke from the Mond producer when the gas-engine was stopped, and also the pressure of the air-blast in inches of water, and whether there was any fine dust or dirt carried into the gas-main from the producer, as was the case with blast-furnace gases.

With regard to the heat-unit used in some parts of the Paper, he was sorry to have to make a protest. In England they were accustomed to thermal units and metric calories, but to introduce a third unit, namely, multiplying pounds with degrees Centigrade was very puzzling. It seemed to him that they must keep either to one or

(Mr. Bryan Donkin.)

the other—the metric or the English, but not a mixture of the two. He hoped the members would agree with him on that point. It seemed a pity to introduce a new unit into the Proceedings. In the interesting Tables giving the properties of steam with saturated gases (pages 98–100), the members were not told what gases were referred to, and, in his opinion, it would be well to add if the Mond gas was meant, or any gas.

Mr. HUMPHREY said the Table was applicable to any gas, and was also of use in giving the weight of steam carried in with the air-blast.

Mr. DONKIN then referred to the calorific value of the Mond gas (page 74), which was given as 88 and 82 lb.-degrees. No doubt it meant pounds English multiplied by degrees Centigrade. Next came the important question of the heating value of gases. In the literature on the Continent and in England, it was now very usual to put, not only the lower heating value of any gas, but also the higher. Whichever was used, it should be exactly stated. He believed the author had since said that all the heating values mentioned in the Paper were the higher calorific values. In England, America, Germany and most countries, the lower heating value was taken, and was always accepted as the right one, and it was only in France that the higher value was adopted both for gas and fuels. This also affected somewhat the thermal efficiency of the gas-engines. In his opinion the question certainly needed settling once and for all by a committee of scientists as the author had hinted at; and he would suggest that the matter be referred to the Gas-Engine Research Committee. In conclusion, the heat efficiency of the engines mentioned in the Paper was an excellent figure of merit, and much quoted both in England and on the Continent. It had the advantage of allowing comparisons to be correctly made, not only for oil, but for various gas-engines and steam-engines. The heat efficiency should, he considered, always be returned per B.H.P. Firstly, so much heat in the oil, gas, or steam was supplied to the engine per B.H.P., so much heat was theoretically

required per B.H.P. according to Joule's equivalent, and the heat
efficiency was the ratio of the latter to the former. It might be of
interest to quote a few results from reliable modern tests upon a
series of heat motors at about full load on oil, gas, and steam-
engines, classed in order of merit as far as possible, and always
taking the heat efficiency per B.H.P. The generators were excluded
and also the steam-boilers. Firstly, the oil-engines headed the list
in order of economy with the highest heat efficiency per B.H.P.,
although not made in sizes larger than 40 to 50 B.H.P. The best
first-class continental oil-engines now gave from 26 to 30 per cent.
heat efficiency per B.H.P.; other modern oil-engines, English and
foreign, of which large numbers were sold, gave from 14 to 20 per
cent. It must be remembered that the oil-motor was much younger
than the gas-engine. Second in the list in order of merit came the
blast-furnace gas-motors now very largely used on the Continent,
utilising gas from blast-furnaces. Engines from 70 to 725 B.H.P., of
continental make, gave a heat efficiency per B.H.P from 20 to 26.
Thirdly, generator gas-engines followed with powers from 100 to
370 B.H.P. The best results to date, including those mentioned in
the Paper, gave from 20 to 25 per cent. heat efficiency per B.H.P.,
both for English and foreign motors. In smaller engines, from 50
to 150 B.H.P., the heat efficiency per B.H.P. was from 14 to 20, or
somewhat lower. These were for English and foreign make.
Fourthly, there was the natural gas in the United States, and for
powers of 40 to 600 B.H.P. Vertical engines with three cylinders
and three cranks of the Westinghouse type gave, according to the
latest tests, from 22 to 25½ per cent. heat efficiency per B.H.P., or
about the same as with generator-gas. Fifthly came engines of English
and foreign make, using lighting gas, with powers varying from
10 to 50 B.H.P. The heat efficiency per B.H.P. varied from 20 to 25 per
cent. in the best modern tests, and many others with smaller powers
from 15 to 19 per cent. Lastly came the reciprocating-piston steam-
engine at the bottom of the thermal efficiency scale. Worked with
saturated steam and first-class motors, compound or triple, of the
best make, steam-jacketed, condensing, with modern steam-pressures,

(Mr. Bryan Donkin.)

TABLE 1 (*continued on opposite page*).

12 *Tests on Gas-Engines with Power- or Generator-Gas, 1890 to 1900.*

On various Horizontal Gas-Engines, English and Foreign, in order of merit of Thermal Efficiency per Brake Horse-power, arranged by Mr. Bryan Donkin, Vice-President.

Powers vary from 57 to 368 B.H.P.

Heating value of Gas 145 to 165 thermal units per cubic foot.

No.	Name of Gas-Engine.	Name of Gas-Generator.	Name of Experimenter.	Name of Town.	Year.
1	Premier	Mond	Humphrey	Winnington	1900
2	Körting	Körting	Meyer	Hanover	1900
3	Crossley	Mond	Humphrey	Winnington	1897
4	Do.	Do.	Do.	Do.	1900
5	Do.	Dowson	Meyer	Zurich	1895
6	Do.	Mond	Humphrey	Winnington	1900
7	Do.	Dowson	Meyer	Zurich	1895
8	Simplex	Lencauchez	{ Delamare-Deboutteville }	{ Pantin, Paris }	1894
9	Deutz	Deutz	Meyer	Bâle	1896
10	Crossley	Mond	Humphrey	Winnington	1894
11	Simplex	Dowson	Witz	Rouen	1890
12	Premier	Do.	Robinson	{ Leyton Elect. Works }	1897
1	2	3	4	5	6

Note.—In French and Swiss Engines, Metric Horse-power has been retained, which is 2 per cent. less than English Horse-power.

TABLE 1.

12 *Tests on Gas-Engines with Power- or Generator-Gas,* 1890 to 1900.

On various Horizontal Gas-Engines, English and Foreign, in order of merit of Thermal Efficiency per Brake Horse-power, arranged by Mr. Bryan Donkin, Vice-President.

Powers vary from 57 *to* 368 *B.H.P.*

Heating value of Gas 145 *to* 165 *thermal units per cubic foot.*

Gas-Engine.					Power.		
No. and Diameter of Cylinders.	Stroke.	Cycle.	Single or Double Acting.	Revs. per Minute.	I.H.P.	B.H.P.	Mechanical Efficiency of Gas-Engine.
Inches.	Inches.			Mean.			Per cent.
two 28·12	30·0	4	S	128	489·0	368·0	75·3
one 21·6	37·7	2	D	101	544·0	341·0	71
two 17·0	24·0	4	S	162	141·6	117·4	83
two 26·0	36·0	4	S	152	378·0	315·0	83
one 16·9	24·0	4	S	165	63·7	57·6	90
two 26·0	36·0	4	S	148	433·0	360·0	83
one 16·9	24·0	4	S	169	51·1	41·1	80
one 34·2	39·4	4	S	100	280·0	220·0	78
two 20·5	30·0	4	S	138	178·0	151·0	85
one 17·0	21·0	4	S	191	38·7	—	71
one 22·6	37·4	4	S	101	110·0	76·0	69
16·0	22·0	4	S	202	160·4	134·0	83
7	8	9	10	11	12	13	14

(Mr. Bryan Donkin.)

TABLE 1 (*continued on next page*).

12 *Tests on Gas-Engines with Power- or Generator-Gas*, 1890 *to* 1900.

On various Horizontal Gas-Engines, English and Foreign,
in order of merit of Thermal Efficiency per Brake Horse-power,
arranged by Mr. Bryan Donkin.

Powers vary from 57 to 368 B.H.P.

Heating value of Gas 145 to 165 thermal units per cubic foot.

No.	Name of Fuel, and Heating value per lb. B.T.U.	Fuel used in Generator per hour, per		Heating Value of Gas per cub. foot. B.T.U.	Gas used per hour, including Ignition, per	
		I.H.P.	B.H.P.		I.H.P.	B.H.P.
		Lbs.	Lbs.	*	cub. ft.	cub. ft.
1	Small Coal	—	—	144 L	52·1	69·2
2	Gas Coke	—	—	129 L	—	81·5
3	Small Coal 12060	0·92	1·26	155 H	65·7	79·3
4	Do.	—	—	162 H	60·1	—
5	Anthracite 14200	1·22	1·36	144 L	—	90·0
6	Small Coal	—	—	169 H	62·7	—
7	Anthracite 14200	1·16	1·47	144 L	—	88·0
8	Anzin French Coal	0·81	1·03	152 H	—	85·0
9	Gas Coke 12963	1·40	1·60	135 L	—	—
10	Slack Coal 12200	1·00	—	155 H	71·0	—
11	Anthracite	—	1·37	167 H	—	85·0
12	Anthracite	1·00	1·20	156 L	80·0	95·0
	15	16	17	18	19	20

* H means Higher Heating Value, and L Lower.

TABLE 1.

12 *Tests on Gas-Engines with Power- or Generator-Gas*, 1890 *to* 1900.

On   various   Horizontal   Gas-Engines,   English   and   Foreign, in order of merit of Thermal Efficiency per Brake Horse-power, arranged by Mr. Bryan Donkin.

Powers vary from 57 *to* 368 B.H.P.

Heating value of Gas 145 *to* 165 *thermal units per cubic foot.*

Heat Efficiency of Engine per B.H.P. per cent.	References, Remarks, &c.
25·6	Humphrey, I.M.E. 1901. 600 H.P. Mond Gas, special air-pump; ⅔ load; driving dynamo direct.
23·8	German Journal of Gas Lighting. On brake. Full power. Double-acting. Gas and air-pump.
22·2	Humphrey to Donkin. Driving dynamo direct. 1 crank.
21·8	Humphrey, I.M.E. 1901. 400 H.P. Mond gas. 1 crank ¾ power. 60 lbs. compression, driving dynamo direct.
21·5	*Zeitschrift des Vereines deutscher Ingenieure*, 21–28 Dec. 1895. Driving dynamo by strap.
21·2	Humphrey, I.M.E. 1901. 400 H.P. Mond Gas. 1 crank. Full load, same as No. 4.
20·2	Z.V.D.I., Dec. 1895. Same engine as No. 5, with less load.
19·8	Report of Delamare-Deboutteville. Driving Flour Mill.
19·3	Z.V.D.I., 24 Oct. 1896. Driving water pumps at Water Works. Bâle.
18·2	Proceedings Inst. C.E., Vol. 129. 25-H.P. engines. Driving dynamo by strap.
18·2	Witz on Gas-Engine, 3rd edition.
14·0	Report of Robinson. Mean results of 4. Engine driving dynamos.
21	22—No. of vertical columns.

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TABLE 2 (*continued on opposite page*).

<div align="center"><i>Six Tests on Gas-Engines with Natural Gas</i>, 1899.</div>

Four tests on Westinghouse vertical Gas-Engines in the United States, in order of merit of Thermal Efficiency per Brake Horse-power, arranged by Mr. Bryan Donkin.

Powers vary from 67 to 606 B.H.P. Heating value of Gas 1,000 thermal units per cubic foot (probably lower value).

No.	Name of Gas-Engine.	Name of Gas-Generator.	Name of Experimenter.	Name of Town.	Year.
1	Westinghouse	Natural Gas	Millar and Gladden	Pittsburg	1899
2	Do.	Do.	Ladley	Do.	Do.
3	Do.	Do.	Millar and Gladden	Do.	Do.
4	Do.	Do.	Do.	Do.	Do.
5	Do. type	Do.	Robertson	Lafayette	Do.
6	Do.	Do.	Do.	Do.	Do.
1	2	3	4	5	6

NOTE.—Natural Gas for Tests 5 and 6 contained 92 per cent. Mehane, 4 per cent. Nitrogen, 2 per cent. CO_2, and about $\frac{1}{2}$ per cent. each of Oxygen, Hydrocarbon, and CO.

(*continued on next page*) **TABLE 2.**

Six Tests on Gas-Engines with Natural Gas, 1899.

Four tests on Westinghouse vertical Gas-Engines in the United States, in order of merit of Thermal Efficiency per Brake Horse-power arranged by Mr. Bryan Donkin.

Powers vary from 67 *to* 606 *B.H.P. Heating value of Gas* 1,000 *thermal units per cubic foot* (*probably lower value*).

Gas-Engine.				Power.			
No. and Diameter of Cylinders. Inches.	Stroke. Inches.	Cycle.	Single or Double Acting.	Revs. per Minute. Mean.	I.H.P.	B.H.P.	Mechanical Efficiency of Gas-Engine. Per cent.
three 25	30	4	S	147	677	606	90
two 11	12	4	S	280	—	66·8	—
three 25	30	4	S	149	621	553	89
three 25	30	4	S	152	449	384	85
three 13	14	4	S	271	92·3	74·5	80
three 13	14	4	S	271	88·8	73·3	80
7	8	9	10	11	12	13	14

(Mr. Bryan Donkin.)

TABLE 2 (*continued on opposite page*).

Six Tests on Gas-Engines with Natural Gas, 1899.

Four tests on Westinghouse vertical Gas-Engines in the United States, in order of merit of Thermal Efficiency per Brake Horse-power, arranged by Mr. Bryan Donkin.

Powers vary from 67 to 600 B.H.P. Heating value of Gas 1,000 thermal units per cubic foot (probably lower value).

No.	Name of Fuel, and Heating value per lb. B.T.U.	Fuel used in Generator per hour, per		Heating value of Gas per cub. foot. B.T.U.	Gas used per hour, including Ignition, per	
		I.H.P. Lbs.	B H.P. Lbs.		I.H.P. cub. ft.	B.H.P. cub. ft.
1	Natural Gas			1,000 ?H or L	8·9	10·0
2	Do.	Do.		Do.	—	10·4
3	Do.	Do.		Do.	9·3	10·4
4	Do.	Do.		Do.	9·9	11·6
5	Do.	Do.		Do.	11·8	14·7
6	Do.	Do.		Do.	14·2	18·0
	15	16	17	18	19	20

TABLE 2.

Six Tests on Gas-Engines with Natural Gas, 1899.

Four tests on Westinghouse vertical Gas-Engines in the United States, in order of merit of Thermal Efficiency per Brake Horse-power, arranged by Mr. Bryan Donkin.

Powers vary from 67 *to* 600 **B.H.P.** *Heating value of Gas* 1,000 *thermal units per cubic foot (probably lower value).*

Heat Efficiency of Engine per B.H.P. per cent.	References, Remarks, &c.
25·5	Sibley Journal, June 1900. Full load. Piston cooled also. Brake on at Works.
24·6	Humphrey, I.M.E. 1901. Full load. Brake at Works.
24·3	Sibley Journal. Full load. Same engine as No. 1. Brake on at Works.
22·0	Two-thirds load. Same engine as No. 1.
16·5	A.S.M.E. 1900, vol. 21. Driving dynamo by strap.
14·2	Do. Less power. Same engine as No. 5.
21	22.—No. of vertical columns.

(Mr. Bryan Donkin.)

and powers varying from 150 to 350 B.H.P., the heat efficiency per B.H.P. was only 12 to 15 per cent. Some few compound or triple engines of 1,000 to 2,000 B.H.P. had come out under test from 16 to 17 per cent. efficiency, and a few large water-pumping engines in the United States, compound and triple, condensing even higher. The younger turbine type of rotary quick-revolution steam-engines of the Laval or Parsons make, pistonless, condensing, also compared very favourably with the piston steam-engines. Thus these six classes of motors using oil, gas, or steam, had varying heat efficiencies per B.H.P. from 12 per cent. with steam up to about 30 per cent. with oil-engines.

Professor WILLIAM ROBINSON said that one could not but appreciate the value of the results of measurements, made under ordinary everyday conditions of working, with instruments carefully tested to a degree of accuracy born of experience in engineering and chemical laboratories. The facts and figures given in the Paper appeared to him to show progress of the greatest importance to all engineers interested in the economic conversion of the heat energy of cheap fuel into useful work. First, with regard to the use of power-gas : he thought all would admit that to Mr. J. Emerson Dowson was undoubtedly due the introduction of a compact plant for making fuel-gas rapidly, which had led to practical success in running large gas-engines economically. Mr. Dowson had many imitators who made slight modifications and gave the plant new names. Dowson gas was made chiefly from anthracite. Good clean coke might be used when the producer was worked carefully. However, the scarcity and high price of anthracite had led to many attempts to use bituminous coal for power-gas, as it was largely used for heating purposes, but there had been difficulty with the tar which clogged the valves of the engine. The coal also tended to cake and form clinker. Now the record in the Paper of economical results obtained in the continuous working of large engines driven by Mond gas produced from bituminous slack proved how thoroughly these difficulties had been overcome. Dr. Ludwig Mond simply used a large quantity of superheated steam in the air-blast to keep his gas-producer at a low temperature, so that no clinker was formed ; the

slack did not cake, the tarry products were converted into gas, and the ammonia was not decomposed. The sensible heat of the gas leaving the generator was utilised to charge the air-blast with water vapour, and convert the latter into superheated steam. Thus the Mond process of gas-making was rational and regular by low temperature regeneration. The ammonia recovery need only be attempted on a large scale, and so long as the price of sulphate of ammonia kept up according to the economic law of supply and demand.

In May and June 1900 he inspected the 1,000-H.P. gas plant at Sandiacre, driving the 500-H.P. "Premier" engine in preliminary trials, before it went to the works of Messrs. Brunner, Mond and Co. He made measurements of the gas and coal used. The heating value of the gas, tested in a Juncker's calorimeter, was 150 B.Th.U.* per cubic foot at 60° F. and atmospheric pressure. The fuel was small bituminous free-burning coal, which gave 12,200 B.Th.U. per lb. in a bomb calorimeter. The engine was running partly loaded. Indicator diagrams were taken which showed a mean pressure of 109 lbs. per square inch in the motor cylinders, and 2 lbs. per square inch in the air-pump. Taking the fall of the gas-holder to measure the quantity of gas supplied to the engine, the thermal efficiency was over 30 per cent. He noted especially the remarkable uniformity in the quality of the Mond gas. That seemed characteristic not only of the Mond gas, made without ammonia recovery in the plant at Sandiacre, but also in the large plant at Northwich, which he had had the pleasure of seeing recently. Samples of gas were taken from the main several times daily, and the chemical analyses and results of tests were recorded in a scientific and methodical manner. These Tables showed very slight change indeed in the quality of the gas. This perfect regulation of the Mond producer was obtained by means of saturated air at a fixed low temperature. The air and steam were kept in constant proportion for different rates of working. That was the most striking feature he had noticed, and it had a very important bearing upon the use of

* Since B.T.U. is generally used as the contraction for the Board of Trade Unit of Electric Supply, he suggested B.Th.U. to stand for British Thermal Unit (lb.-degree Fahr.).

gas from the engines, by (1) the addition of heat, (2) the reduction of steam required, and (3) greater volume of gas made from 1 lb. of slack. Mr. Dowson added for the production of steam 17 per cent. of the fuel gasified; and it appeared that one-eighth or 13 per cent. for coal in the boiler would be ample for the Mond plant without ammonia recovery. After all, slack was a very cheap fuel, and the cost of each heat-unit in the Mond gas as supplied to the engines was the main point for the gas plant in actual practice, next to the cost of the useful work given out by the engines.

He was glad to see that the author clearly pointed out the difference between the total I.H.P. and the net effective I.H.P. The " bottom loop," or light spring indicator diagram, showed part of the cycle, since it gave the back pressure during the exhaust and charging strokes, and therefore should be deducted, as well as the work spent in the air-pump, from the ordinary indicated H.P. to give the net effective I.H.P. He did not wish to criticise engines, the first of that size made in this country, which had produced such remarkable results in economy of fuel. The indicator diagrams and figures clearly showed that in the 400-H.P. Crossley engine the loss by fluid resistance and throttling of the gas- and air-admission was 7·7 per cent. of the total indicated power. The quantity of gas and air in the charge had to be kept down to prevent premature ignition by too high compression and temperature in the cylinder, because the piston was not cooled by water circulation and air. The clearance space was practically in the same proportion (21 per cent.) of the total volume of cylinder in both engines, yet the charge was compressed to 40 lbs. per square inch higher in the " Premier," which gave a mean pressure of 109 lbs., as compared with 51 lbs. per square inch in the Crossley engine. In the " Premier " 500-H.P. engine the " bottom loop " diagrams only came to 3 per cent. of the total I.H.P., and if to this were added the negative work of the air-pump 4·3, the total fluid loss, 7·3 per cent., was less than in the Crossley engine, and with the further advantages of scavenging. Again, the difference between governing with the ordinary Otto cycle engine and in the positive scavenging engine was very marked. Indicator diagrams showed an increase in the mean pressure of 8·5

(Professor William Robinson.)

to 9 per cent. after a missfire in the 400-H.P. Crossley engine. On the other hand, in the "Premier" engine, where the scavenger air cleared out the residual products after every explosion stroke, the variation was only about 1 per cent. and scarcely noticeable. This was a very important matter. The control of ignition by the electric spark, as in the "Premier" engine, gave more economical results, whilst a change in the time of firing the weaker charge would alter the power and economy, with all other conditions the same. If the point of ignition could be varied, it would be quite possible to govern by varying the strength of the mixture in the charge with satisfactory results, especially with rich gas. The slight loss in efficiency of the 100-H.P. engine during 1899 (page 90) appeared to be due to the method of governing by throttling the gas-valve. When working with a constant point of ignition, suitable for a certain richness of gas, as the gas varied in quality, became "poor" (of low calorific value), or by throttling formed a weaker mixture in the cylinder, the combustion became slower and the mean indicated pressure greatly reduced. The actual composition of the mixture in the cylinder also depended upon the nature and varying amount of the residual products occupying the clearance space before the charge was admitted.

With the ordinary Dowson gas-producer the composition of the gas changed every time the producer was fed with fresh fuel, and as the pressure of steam varied in the little boiler. It was also necessary to keep sufficient depth of fuel to prevent the steam passing undecomposed through holes or channels, especially in the large sizes of these gas-producers. The chief trouble was the formation of clinker, which caused the calorific value of the gas to vary greatly, and necessitated clinkering every day or two. In a test during two days the Dowson producer was charged regularly with good anthracite, and the pressure of steam was kept constant, yet he observed the gross heating value of the gas to vary from 170 to 137 B.Th.U. per cubic foot. The corresponding change in the mean indicated pressure in the engine was still greater. On the normal indicator diagram, Fig. 45, the mean pressure of 80 lbs. per square inch was reduced by poor gas, and retarded combustion to 60

and even less than 40 lbs. per square inch, when working ten hours after clinkering.

FIG. 45.   *Indicator Diagrams.*
100-H.P. Engine working with Dowson Gas.

Mean Pressure.

A. Normal Diagram . . . = 80 lbs. per sq. inch.
B. Rich Gas (Pre-ignition) just after clinkering} = 70 ,, ,, ,, ,,
C & D. Poor Gas (late burning)} = 60 ,, ,, ,, ,,
10 hours after clinkering . } = 40 ,, ,, ,, ,,

Next, the gas-producer was changed over and the gas supply came from a fresh one just after clinkering; with the same conditions in the engine there was premature ignition, and although a high explosion was obtained it fell off more rapidly, and the mean pressure came to only 70 lbs. per square inch.   The performance of an engine working on the ordinary Otto cycle depended greatly on the quality and pressure of the gas supply, and it was essential for steady running to have as little variation in these as possible.   Even with coal gas, the effect of the difference in the pressure and quality of the gas admitted into the cylinder had been frequently observed when testing engines in the morning and evening.   The variation in the weight of combustible gas and air taken into the cylinder was a vital question affecting the action of large engines working on poor gas, and set for ignition at a fixed point in the stroke.   The difficulty was partly, though not completely, overcome by the positive scavenger, which helped to cool the cylinder and swept out the residual products, thereby reducing the risk of pre-ignition and allowing greater compression of the charge, so that a greater mean pressure could be steadily maintained, giving more power and higher efficiency.   He would illustrate the point :—

(Professor William Robinson.)

LOSS OF POWER BY HOT CYLINDER AND POOR GAS.

| | Cylinder walls. | | Poor Gas. |
	Normal.	Hot.	
Mean Pressure . . lbs. per square inch	80	60	50
Indicated H.P.	100	75	62·5
Engine Friction H.P.. . . .	13	13	13
Brake H.P.	87	62	49·5

Suppose an engine, running at a constant speed of 160 revolutions per minute and making 80 explosions per minute with gas of 160 B.Th.U. per cubic foot, gave 100 I.H.P. for a mean effective pressure of 80 lbs. per square inch when the cylinder was at normal temperature. When the power spent in engine friction was 13, or the mechanical efficiency 87 per cent., the brake horsepower would be 87 H.P. He had observed the temperature of the explosions inside the cylinder, with a platinum-wire thermometer, over 1,500° C., and a fine platinum wire of the Callendar platinum resistance thermometer was fused, which meant that 1,775° C. or 3,200° F. was reached. This momentary high temperature caused partial dissociation of the combining gases, and heated the surface of the combustion chamber, which gave back part of the heat to the gases during expansion. As the gas-engine was made larger the cylinder walls must necessarily be thicker, the heat took longer time to be conducted through the metal to the water jacket, and the skin of the metal became very hot, nearly the temperature of combustion for a certain time. Experiment showed the loss of heat to the jacket was less in proportion in large engines than through the thinner walls of small cylinders. Another reason was that the area of the cooling surface increased as the square, whilst the volume or weight of gas enclosed and therefore the heat of combustion increased as the cube of the linear dimensions. The cyclical changes of temperature were greatest on the skin or inner surface of the cylinder walls, and the large masses of metal retained part of the

heat. As the combustion chamber and cylinder became gradually heated, in the ordinary Otto cycle engine, so did the incoming charge, and less weight of gas was taken into the same space. The result was a lower mean effective pressure, say of 60 lbs. per square inch, obtained during the cycle. That meant three-quarters of the indicated power was developed, and if the friction remained the same, the engine gave only 62 B.H.P. Now, let the heating value of the producer gas fall from 160 to 140 B.Th.U. per cubic foot, the mean pressure came to about 50 lbs. per square inch, and the I.H.P. would be about $62\frac{1}{2}$. The result was $49\frac{1}{2}$ B.H.P. or perhaps less. In other words, there was a loss of 43 per cent. in power due to the heating of the engine and to the variation in the quality of the gas. Hence, in large engines it was highly desirable that there should be some means of keeping the charge of gas and air as cool and pure as possible and getting rid of the products of combustion by positive scavenging. The consumption of water for cooling the cylinder and piston of the " Simplex " engine was given (page 102) 15·8 gallons per B.H.P. hour. The quantity of oil as lubricant was not recorded for the 600-H.P. engine ! The crude gas from *coal-fed* blast-furnaces must be thoroughly washed, scrubbed, and purified to remove the tar and make the gas clean and fit for use in the engine cylinder. The tar appeared to be carried by the gas like the thin film of exceedingly minute bubbles, and when these collapsed or burst, the tar was deposited. The stream of gas had to be thoroughly broken up through sawdust or gauze filters.

He considered the Paper of great importance, because the stage was now reached when large engines would be more and more used, with clean and cheap fuel gas of uniform heating value. The application of Mond gas in large engines promised to inaugurate a new era in the generation of power. The results at Winnington with the " Premier " engine showed, so far as he was aware, the greatest economy hitherto attained in practical working from common bituminous slack. He congratulated the author on the useful information laid before the Institution.

Mr. W. J. CROSSLEY said that, as he had already spoken once (page 122), he would be very brief indeed. He regarded the Paper

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as of so much importance, that he hoped the Members would forgive him if he appeared a little hypercritical as to the way the figures were arranged. They were of such absolute importance to his firm that he thought it his duty to point them out. At the first meeting at which the subject was discussed, the thermal efficiency of the "Premier" engine was given on what was called the lower scale,* while that of the Crossley engine was given on the higher scale. He had been in correspondence with the author on the subject, who had very kindly promised to put the matter right, but he thought he ought himself to point out what an extreme difference it made to his firm. In the supplementary Paper which had been published, it would be found that the letters "H" for higher scale and "L" for lower scale were put opposite the figures, but he did not know whether even that made it quite intelligible to "the man in the street." First, taking the example before them, he found that the "Premier" engine put on the lower scale gave a thermal efficiency of 25·6, whereas in the same Paper his firm's engine, put down on the higher scale, came out at only 21·8. If those two figures were arranged in parallel order it was very disappointing as far as his engine was concerned, but if his engine was put also on the lower scale it came out at 24·4, which was only 1·2 behind the "Premier" engine; and as the author had been so kind as to add the 1 per cent. improvement of his engine which he gave him on the last occasion, his engine was already there, because it was only 0·2 behind the "Premier" engine, in his opinion a magnificent performance, considering the fact that the compression was perhaps even less than half the "Premier" compression, and that the engine was so much more simple. Another point he wished to mention was that his 60-N.H.P. engine, which had been working 3 years, if calculated on the lower scale would now come out at 24·9, a good performance, it seemed to him, for an engine of that age and size. It seemed to him also that if his engine were calculated, as if it had

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* The author gave the thermal efficiency of the "Premier" engine calculated on *both* the "higher" and "lower" scales (Appendix V, Table 5, page 86).

120 lbs. compression, the efficiency would be brought up to 28 per cent. at least.

Another matter he wished to suggest was that the figures should be arranged in order of merit. He found in the Tables appended to Mr. Donkin's remarks (pages 154–157) certain figures inserted which were not quite fair. The first two engines were the " Premier " engine, which at the present time certainly ranked first in order of merit, and then came the " Körting " engine. The " Premier " engine and the " Körting " engine were reckoned out on the lower scale, while the two Crossley engines which followed were worked out on the higher scale. If his engines were reckoned out on the same scale as the others, instead of ranking third or fourth, they would rank second and third.* In these days of exalting the German nation he really did not see why the Institution should put the Germans a peg higher than they ought to be placed. He only wanted what was exactly and strictly fair. Again on page 155 of Mr. Donkin's Tables he found that the mechanical efficiency of the " Premier " engine should be 75·3 per cent. instead of 81 per cent. as printed.† He was sorry to have to criticise the figures of his opponent, but he must say the best he could for his own firm. The difference was caused by not reckoning fluid resistance in the case of the " Premier " engine. He thought that as all the other engines were debited with fluid resistance, the " Premier " engine should also be debited with fluid resistance, and that the alteration should

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* Mr. DONKIN, in commenting on the above remarks, said that, if in all the different tests the higher and the lower heating values of the gas used were reported, there would be no difficulty, but unfortunately such was not the case ; some authorities gave only one value and some only the other. The heating values actually given could only be taken as a basis, and this affected somewhat the order of merit or the thermal efficiency in the Tables. The Tables showed exactly which heating value was returned and used. The load on the engine also affected the thermal efficiency. No. 1 engine in the Tables was worked only at two-thirds load, and No. 4 at three-quarters load. Generally, for the same engine, the greater the load the higher the efficiency up to a certain limit.

† This correction has now been made.

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be made in the Paper. He thought it was also important to show that in that class of engine if the fluid resistance was not reckoned, and the mechanical resistance taken simply, it would be found that the friction loss was $18 \cdot 78$ per cent., whereas in the case of his engine it was only $9 \cdot 33$ per cent., showing that that form of scavenging, though undoubtedly a very thorough and good form, had to be paid for. His firm considered that form of scavenging many years ago, and decided not to adopt it for that very reason, because it seemed to them to be likely to be too expensive in working, whereas the form they adopted cost nothing. He was not able to follow what Professor Robinson said with regard to the fluid resistance of their engines (page 165). He was willing to admit that in this particular case the fluid resistance of his engine was absurdly great, and that they would very greatly improve the engine if it could be lessened, because a much larger charge could be brought into the cylinder. He wished to admit that at once. With regard to Professor Robinson's criticism as to the faults and vagaries of gas-engines, he asked himself the question, " had steam never gone down on a steam-engine : had they never had any trouble with the firing of boilers, and the keeping up of steam?" On certain occasions he had seen gas-engines behave themselves disgracefully, when the man did not fire the generator properly, and did not clinker it, so that bad gases were obtained ; but they did not reckon to work under those conditions nowadays. They had run their engines with Dowson gas for nearly 20 years, and had had no trouble of the kind described, and had found, as Professor Robinson had said, that the quantity of the Mond gas was extremely steady and most satisfactory.

Mr. E. B. ELLINGTON, Member of Council, said that, while he desired to offer one or two criticisms on some points of the Paper, he also wished to add his testimony to its very great value as a whole. He thought it would mark an era in the development and use of large gas-engines in England, and in reference to gas production would also mark an era in what he might call the mechanical use of low temperatures. It would appear that it was only in that direction

that any great economy in thermo-dynamic machines remained to be obtained.   The case for the use of gas-engines on the point of thermal efficiency seemed to be so very good that he rather regretted that in the Paper a certain line of argument had been adopted which contained a fallacy.   The fallacy was in connection with the sulphate of ammonia process and the Mond producer-gas.   It seemed to him that where there were two products from a series of operations, the only basis upon which any definite conclusions could be arrived at was the very reasonable assumption that the value of the two products was what they were both worth in the market, especially in dealing with the matter from a scientific point of view. He thought, therefore, it was a mistake to credit to the cost of the coal the net value of the sulphate of ammonia produced.   That the line of argument adopted by the author had been rather unfortunate was evidenced by the fact that in Appendix IX (page 93) he had made the cost of coal a minus quantity.   There must be something wrong, though the result was arithmetically correct.   It was clear that there must be many other ways on the same method of reasoning by which fuel could be obtained for nothing.   A colliery could be purchased, and half the coal sold at a large profit, and then it might be said that the rest of the coal used by the owners cost nothing. He did not think that was a proper way to deal with the matter, and it had led to this difficulty in dealing with the figures in the Paper —that the cost of coal was taken at several different prices : in one of the Appendices it was taken at 10s., in another at 5s. a ton, and in another at 12s. a ton.   The figures were all compared, and it was very difficult indeed to follow them.   He referred particularly to Appendix X (page 96), in which actual results obtained in various central stations were compared with the actual results obtained with the Mond gas.   There it would be found that $0 \cdot 048d.$ was taken as the cost per unit of the electricity produced with the Mond gas, $0 \cdot 21d.$ as the cost of the continuous running of an ideal central station, $0 \cdot 385d.$ a good actual result, and $0 \cdot 778$ as the actual average results of running with steam-engines in practice.   But it would be found that the slack was taken at 5s. a ton, and coal at 12s. a ton, whereas the thermal value of the two fuels given would make the relative

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prices 10s. and 12s. He thought, therefore, that that price of
0·048d. ought, in comparison with the other figures, really to
be at least doubled. With regard to the comparison, he would like
to give the actual results he had himself obtained with steam. He
would give the last complete returns which he had from the central
hydraulic-power station of the London Hydraulic Power Co. at
Wapping. He took the coal at 10s. a ton, which was a very fair value,
and corresponded precisely with the price paid in London over a series
of years. In order that there should be no confusion, he would give
the figures in electrical units. The output of the Wapping Station
in 1899 was 295 million gallons at 780 to 800 lbs. pressure per
square inch, which was equivalent to about two million units. The
cost of coal for the whole year was per unit 0·215d., oil, water
(including the sum paid for water rights), and stores, 0·056d.,
wages 0·138d., and repairs 0·056d., or a total of 0·465d. per unit
generated, say 0·5d. per unit sold at a short distance from the
station. It would be noticed that the amount for coal, 0·215d., was
nearly the exact figure given by the author as the ideal of a steam-
station with continuous running to compare with a gas-engine and
Mond producer-gas. The I.H.P. of the Wapping station was only
1,200. The load factor of this station, instead of being 100 per
cent., that is, with continuous running, was only 39 per cent.,
calculated on the maximum ¼ hour output during the year; and the
figure 0·215d. represented only 74 per cent. of the trial efficiency of
the plant. He submitted that the figure 0·048d. ought to be doubled
to provide for the price of coal of the comparative figure in steam-
engines, and ought to be increased by a further 25 per cent. in
order to compare with the load factor of 39 per cent. If the coal
used for raising steam in the Mond producer was also included, a
further 25 per cent. would have to be added, and the total cost
would be 0·15d. per unit instead of 0·048d. The coal of all the
stations of the Hydraulic Supply Co. in London in 1899, with a load
factor of 33 per cent., worked out to 0·25d. per unit, not a very large
difference in money value. With regard to the question of load
factor, he wished to ask the author whether he had not taken in

Appendix IX (page 93) the cost of the fuel for the gas-engine the same for all the load factors given in the Table.

The fact seemed to be that the coal economy to be derived from the combination of Mond gas and large gas-engines was almost exactly the amount represented in the difference of the thermal efficiency of a steam-engine and a gas-engine. The engines at Wapping on the trial he referred to gave a thermal efficiency of 15 per cent. Taking the gas-engine at 25, it would be found—if he was right in his way of looking at the figures—that the proportion 25 to 15 represented about the difference in the cost of the coal of the different systems of working, and that therefore speaking generally it would appear that the efficiency of the boilers and the producers was just about the same. In considering the question of using producers and gas-engines in place of boilers and steam-engines, practically the question arose—what was the capital cost? How was it that with a central-station cost of only $\frac{1}{2}d$. per unit, it was impossible to supply energy over any large area at less than an average rate of 3d. or 4d. per unit? The difference in value of coal between the system proposed and boilers and steam-engines was about one-tenth of a penny per unit, and therefore was not sufficient to make any very large difference in the cost of power supplied to the public over a large area. The main factor governing the cost was the capital. The cost of the capital was far larger than the station cost, and in addition there was a large amount for rates, which formed in fact part of the capital charges. He quite agreed with the author that all those things were properly omitted from the Paper; they could not be dealt with. But as they were omitted, it would have been better also to omit most of the comparative figures, because as they stood they were misleading. It sounded very encouraging to be able to obtain energy at a small fraction of a penny per unit as the cost of fuel. But though coal was an important factor in the production and distribution of energy over large areas, it was after all not by any means the most important factor. The rates alone were often greater than the coal cost, even with steam-engines, and rates were constantly increasing. The

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capital cost was two or three times the whole station cost, and beyond that there were all the general charges.

Load factor was an extremely important item as affecting the capital charges. The exceptionally good load factor of 33 per cent., which was obtained with the London Hydraulic supply of energy, was due to the large amount used during the night. At present about one-third of the day supply was generated and used between the hours of 6 p.m. and 6 a.m. He was afraid that general supplies of energy for lighting and power were not likely to secure anything like so good a load factor as was contemplated by the author.

Mr. EWING MATHESON said some interesting information had been given to the meeting by those who were concerned in the manufacture of producer-gas and gas-engines. There was, however, another class of people, of whom he was one, namely the users of those engines, that wanted more information. He was concerned in the use of considerable powers in the Midlands and Northern counties, and was on the point of ordering some large gas-engines; but before spending his money he had taken some pains to inform himself, and first of all, in regard to what was taking place on the Continent. Although he did not want to go to Germany, Belgium, or France, he would like to know what was going on there. The information he had obtained differed from that which Mr. Bryan Donkin had given them, for though he found there was a very large gas-engine on show, there was no evidence to prove that it was a practical working engine. The engine he referred to was one of about 1,000 H.P., and he had no doubt was the one which Mr. Donkin had in his mind, and which had been exhibited—or one like it—at Paris last year. The question resolved itself into two, namely the gas and the gas-engine. To obtain information he had made a pilgrimage to Winnington to see what was being done there with gas and gas-engines. He only looked at the subject from the point of view of a mechanical engineer, and not as one who knew much about producer-gas. When Mr. Dugald Clerk spoke at a previous meeting, he thought that he (the speaker) was going to be further enlightened. Mr. Clerk described

the Crossley engine at Winnington, and related how it had not got
a direct scavenging arrangement, and had not a water-cooled piston,
and he then went on to explain why it had not a water-cooled piston.
In regard to this, Mr. Clerk explained that, though it was a most
desirable thing in the abstract, yet supposing the water-cooled
arrangement broke down, and the piston got hot, dreadful things
might happen; for such a catastrophe might stop the engine.
Having heard Mr. Clerk's opinion on the Crossley engine, one
naturally expected a description of the other engine—the " Premier "
engine; but Mr. Clerk sat down, and never said a word about it.
Even now he, the speaker, would be glad to hear someone deal with
the merits of the " Premier " engine, for he had not spent his
money yet, or placed any order, and before doing so wanted all the
information he could get on the subject.

In regard to large engines, there seemed to be two essential
conditions of success—the scavenging arrangement and the water-
cooling. First, with regard to the scavenging, he had made enquiries
and had visited all the large engines he could see. He found that
engines of over 100 H.P., if they were not well scavenged, got foul
after a few hours' running, and lost a considerable proportion of
their force. On the other hand, he had seen a " Premier " engine
that had been running day and night for a week—a pretty good test
for a gas-engine—and he was credibly informed that at the end of
that period it showed as good a diagram and as good an effective
force, as if it had only just been started. He would like to hear
from Mr. Crossley whether one of his engines of large power would,
if worked continuously, give as good a diagram at the end of a day
or week as it did at the end of the first hour. He fully believed in
the Crossley engine of moderate power, and had several at work.
With regard to the cooling of the piston in their large engine at
Winnington, he noticed a peculiar device. There was an arrangement
of a blower and a fan, and pipes blowing in air into the piston to
cool it, but it did not keep down the temperature so well as the
water-cooler. He thought it was a pity in a discussion of the kind
now before the Meeting, which was evidently considered by all
members of the Institution as one of importance, that the matter was

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not thrashed out a little more closely, because there were many
people—he was only one—who were waiting to know what to do.
They wanted power, and they desired it cheap, and wanted the
proper gas in the proper gas-engine. With regard to gas, if he was
situated in the neighbourhood of Cardiff he should go in for the
Dowson gas, but unfortunately the two concerns he was interested in
were situated one in the Midlands and one in Yorkshire, where
Welsh coal could not be obtained cheaply ; and so he had decided to
use Mond gas, which he thought was the most effective, even
although in his case it was not to be made on a large enough scale
to get the sulphate of ammonia profitably. The author seemed to
have devoted himself more to the question of gas than to the
question of gas-engines. If he could in reply enlighten the members
upon the points which he, the speaker, had drawn attention to, it
would be of great advantage, as those points had not had the attention
they deserved.

Mr. J. H. HAMILTON thought that the gas-engine had now
fairly started on the career of success which had so long been
prophesied for it, and thanks to the enterprise of Messrs. Brunner,
Mond and Co., they in this country had an opportunity of comparing
what they could do with that accomplished by foreign makers of large
engines. The Paper was so full of information of a useful kind,
that it was sure to take a prominent place in gas-engine literature,
and to advance the cause of gas-power which was now a subject of
national importance. He was present during the test of the
" Premier " engine, and was much struck by the fact that no expense
seemed to be spared in order to get accurate figures. The
measurement of the gas by a calibrated meter placed these tests on a
higher plane than those of other large engines, in which the
consumption could be taken over a few minutes only by the fall of
a gas-holder. During this test there were nearly 29,000 admissions
of gas, and all these charges were ignited without a failure or false
explosion, nor was there a single back-fire during this time. He
thought this result, which could not be said to be a common one,
was due to the efficient scavenging action in this engine, the pump

cards showing that after every explosion a volume of air equal to $3\frac{1}{2}$ times the capacity of the combustion chamber was discharged into the latter, whereof $2\frac{1}{2}$ volumes passed out of the exhaust, so that the scavenging could hardly fail to be complete.   The " Premier " engine was the first 4-stroke scavenging-engine on the market, and the present example was the result of ten years' experiment with this type.   It was the only real scavenger-engine, and as such, no less than in view of the results it had accomplished, he thought they might be interested in some points in the design which he would point out.

A section of the engine was given on Plate 3, and from this they would see that the large end of the front piston not only acted as the piston of the air-scavenging pump, but also as a guide for taking the lateral thrust of the connecting-rod, and so relieving the motor piston of that pressure, which tended to wear it oval.   Moreover, by reason of this large end working in a cool cylinder, which was kept flooded with oil on its lower side by the oil-retaining well in front, and the fact that the bearing surface was very large, the wear was reduced to a minimum.   The large end also gave ample space for the gudgeon-pin bearings which were fitted one on each side of the connecting-rod, the pin being fixed in the latter.   These bearings had about twice the surface usually allowed, and were in a very accessible position for adjustment and lubrication, and as they were not heated by proximity to the nearly red-hot end of a piston, as in the usual construction, they could be lubricated efficiently.   The large end of the piston also served for the attachment of the side rods which passed through it close to the ends of the gudgeon-pin, which thus received the thrust from the back piston in a direct manner.

The grid valve over the guide cylinder admitted the air both for the scavenging and for mixing with the gas in the motor cylinders. At each out-stroke air was drawn through this valve, part going to the scavenging cylinder and part to whichever of the motor cylinders happened to be making its suction stroke.   On the return stroke a portion of the air drawn into the scavenging cylinder was allowed to pass back into the air-pipe, the grid not being closed till about one-

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third of the stroke had been made. After that the air was compressed into the clearance space and passages, until the crank reached the position shown on the section, and then the admission valve of that cylinder, which happened to be making its exhaust stroke, was opened, allowing the scavenging air to be discharged during the remainder of the back-stroke. In a scavenger engine it was essential that there should be a free passage for the scavenging air, and, indeed, in any engine governing by cutting out ignitions, the air passage having to pass the whole volume of the cylinder, when no gas was taken in, should be unrestricted at such times, although it was necessary for it to be more or less blocked when a charge of gas was being taken in. The manner in which this was accomplished in the " Premier " engine would be seen on reference to the section of the admission- and gas-valves on Fig. 14, Plate 3. It would be seen that the gas-valve was annular, and had attached to it rings which partially blocked the air-ports when the gas-valve opened. Thus while the gas-valve was closed there was an ample air passage, but when opened the passage was sufficiently restricted to cause the proper quantity of gas to be taken in. Moreover, the gas and air streams were symmetrical and presented a large area of contact, thus ensuring complete mixing. That this arrangement was efficient was shown by the fact that the fluid losses in the " Premier " engine were less in proportion to its power than those in the Crossley engine, although the former was a scavenger engine and the latter was not. Thus the " Premier " engine working at full power indicated 650 H.P. with a fluid loss of 36 H.P., whereas the Crossley engine indicating 432 H.P. had a fluid loss of 27·8 H.P. The fluid loss of the " Premier " engine increased only to a very small extent when running at light loads, and under such conditions it was far less in proportion than that in the Crossley engine. In this latter engine the air passage was permanently blocked, with the result that when cutting out gas-charges the resistance was excessive, as would be seen by referring to the light spring cards, Fig. 3 (page 48), when taking air only. If the drop in the suction line were due to the air pipe being too long, as suggested by Mr. Crossley (page 123), this line would rise towards the end of the stroke, but it did not do so, and

everything pointed to a too restricted passage. The air pipe of the " Premier " engine was equally long, and was also fitted with a muffling arrangement ; the above described effect could be clearly seen on the pump card in which the suction line crossed the atmospheric line before the end of the outstroke.

Another point about the " Premier " design was the equal alternations of explosions and the compression every back-stroke. It was intended that the compression should be high enough to bring the moving parts to rest, and thus to act like the air-buffer in the Willans engine and prevent knocking at the joints. The condition to be fulfilled to accomplish this was that the combined diagram for the inertia forces and compression pressures should not rise above the zero line. They would see in Fig. 31 (page 66) in the lower figure the combined diagram both for the forward and backward stroke. This showed that at 125 revolutions per minute there was a pull on the connecting-rod bolts near the back end of the return stroke equivalent to a pressure of 10 lbs. per square inch on the piston. To avoid this altogether it was necessary to run the engine at 120 revolutions per minute or less. The corresponding diagram for the Crossley engine was given in Fig. 26 (page 60), and showed a pull on the connecting-rod bolts equivalent to about 55 lbs. per square inch of piston at 150 revolutions per minute, corresponding with 35 lbs. at 120 revolutions per minute. It was the desire to get smooth running by preventing a reversal of pressures that caused the speed to be limited below 130 revolutions per minute, the knock being slight for the small pull on the bolts which took place below that speed.

With regard to the cyclic variation in speed, he would point out that the dimensions and weights of the flywheels on the " Premier " and Crossley engines were the same, but that the former was 50 per cent. more powerful when running at five-sixths of the speed of the latter. It would be seen (pages 82–86) that for the Crossley engine running at 150 revolutions per minute, the maximum displacement of the real wheel from the imaginary one was − 0·29 to + 0·38 degree, a total of 0·67 degree, whereas in the case of the

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"Premier" it was from $-0\cdot30$ to $+0\cdot41$, a total of $0\cdot71$ degree. Now suppose the weight of the "Premier" flywheel were the same in proportion to its power as the Crossley wheel, and that by increasing the diameter of the wheel the surface speed was made the same as that of the Crossley, the total variation would be $0\cdot33$ degree, or less than half that of the Crossley engine. The variation would be still less, if they took for a basis the power developed each impulse, instead of the I.H.P. for the increase of weight in the wheel; and he thought this clearly showed the superiority of the "Premier" cycle mentioned by the author. The "Premier" flywheel had also a very strongly fastened rim, the merit of the design being that the stresses were more uniformly distributed over the section than in any other design. Their recent practice was to use larger wheels.

Referring to the combined diagrams on Fig. 31 (page 66), they would see the beneficial effect which the inertia of the reciprocating parts had in modifying the pressure on the crank and equalising the turning moment; for whereas the maximum pressure on the indicator card was about 330 lbs. per square inch, the pressure transmitted to the crank was only equivalent to 230 lbs. The mean pressure was 108 lbs. per square inch, and therefore the maximum pressure on the crank was $2\cdot13$ times the mean pressure. The figures for the Crossley engine were: maximum pressure on indicator card about 240 lbs. per square inch, maximum pressure transmitted to crank about 180 lbs. per square inch, maximum pressure three times the mean pressure. One would expect that with such high mean pressures and comparatively low maximum pressures the "Premier" engine would have a high mechanical efficiency, and therefore he was rather disappointed that there was a loss of 120 H.P. in frictional and fluid resistances. But the engine was new when the test was made, and the latest test by the author showed the loss was reduced to 106 H.P.; and as the full load power is 650 I.H.P. the mechanical efficiency, including fluid losses and friction, came out at $83\cdot8$ per cent., or if fluid losses were deducted the mechanical efficiency would be $88\cdot8$ per cent. He hoped there would be an improvement on that figure after further running.

He wished to take exception to Mr. Atkinson's statement (page 149), that so far as economy went the Crossley and the " Premier " engines were alike, and that the simplicity of the former made it a better engine. In the first place the figures Mr. Atkinson mentioned for thermal efficiency per B.H.P. were for the Crossley engine at full load and for the " Premier " at two-thirds load. Had the " Premier " engine been working at full load, the thermal efficiency would have been 25 per cent. per B.H.P. as against 22·5 per cent., the improved figure for the Crossley engine, that is to say an 11 per cent. better result. As to complication, the " Premier " engine certainly had the scavenger cylinder, which however had sufficient mechanical advantages to justify its use, independently of its function as a scavenger pump. Beyond this there was a crosshead and two side-rods to set against a gudgeon-pin and a double-jawed connecting-rod; and he did not think there was much to choose between them so far as complication was concerned. But the " Premier " engine design allowed of an ample bearing surface in the connecting-rod brasses, which were 14 inches long in the engine at Winnington; and to get this bearing with the Crossley design the crank-pin would have to be 28 inches long. He thought he was safe in saying that no such proportions were in vogue with Messrs. Crossley Brothers. Their engine had also two governors, two sets of gear wheels, and two side-shafts and bearings, so that on the whole there was not much difference in the complication of the two engines. He was glad to hear from the author that the latest test of the " Premier " engine showed a marked improvement in economy, the figures now being 33·65 and 37·76 per cent. thermal efficiency per I.H.P. on the higher and lower value of the gas; and these corresponded with 28·2 and 30·5 per cent. per B.H.P. at full load, which was a record for an explosion engine.

Mr. Dugald Clerk had described (page 146) the horns of the dilemma upon which the gas-engine maker was placed in designing the piston, but for his part he had chosen the water-jacket alternative instead of making the piston $\frac{1}{8}$ inch too small for the cylinder ; " Premier " engines had been fitted with water-jacketed pistons for $3\frac{1}{2}$ years, and water-cooled exhaust-valve for 5 years. His firm had

(Mr. J. H. Hamilton.)

therefore had as much experience in water-jacketing as any continental firm, and had now got over the difficulties which every new departure entailed. Surely the nation had already lost sufficient ground in other industries for lack of enterprise to teach it the lesson that the industrial battle was for those who kept in the front, and not for those who waited to see what others were doing. The problem of saving coal, which was our national capital, was pressing and vital, because its successful solution meant not only greater present prosperity, but a postponement of the inevitable day when lack of coal would paralyse every industry. Gas for power and heating offered the most promising solution, and the saving already attained with Mond gas in a few installations would, if applied all over the country, do more towards maintaining their position in the markets of the world than any of the panaceas which had been offered. Therefore the author had done good service in so ably putting this subject before the Institution.

Mr. W. C. Goodchild said that some of the members probably knew that in 1894 the Midland Railway Co. put down a gas plant at Leicester, which had been running very successfully. Mr. Langdon mentioned the matter in a Paper which he read before the Institution of Electrical Engineers in 1895,* and with that gentleman's permission he was enabled now to give some up-to-date figures. He would first say that the capacity of the station had been somewhat increased since the first installation. It started with six engines aggregating 250 B.H.P.; but during last year four had been changed, so that the total B.H.P. was now 400. There were two gas-generators which had also been increased in capacity by an alteration in the fire-bars. The load factor of the station was only 34 per cent., and the output per annum was about 350,000 units, so that the figures did not compare very favourably with anything the author would show. The coal for the last half-year came to $0 \cdot 34d$. per unit, and the weight was $3 \cdot 1$ lbs.; for the previous half-year the figures were

* Proceedings, Institution of Electrical Engineers, 1895, vol. 24, page 284.

respectively $0 \cdot 327d$. and $4 \cdot 3$ lbs. That was a good result; they hope to get one much better. For the half-year ending June 1898 coal only cost $0 \cdot 2d$. per unit. Some trouble had been experienced with pre-ignition, owing to the higher compression compared with the old engines. The new engines had a compression of 85 lbs. to the square inch, whereas the old engines only had 60 lbs. to the square inch. Pre-ignition in the old engines was unknown. The new engines were of the scavenging type, so that if there were any waste products left, there would be a better chance of clearing them out. There was no battery in the station, so that the engines had to run the whole day, very often at one-tenth load for one engine, and the economy under those conditions was therefore not likely to be very good. It might interest the members to know that the Midland Railway Co. had ten other stations at different parts of their system using steam-engines. Most of those stations had similar outputs and load-factors to the Leicester plant, yet the gas-engine station only used one-third of the weight of coal per unit, and the cost was one-half, owing to the fact that much more had to be paid for anthracite coal than for ordinary steam coal. He would like to ask the author what was the compression per square inch in the engine which he quoted in Appendix VII (page 88) of 60 N.H.P. (Crossley engine). There had been some very good runs on that, lasting up to 138 days, but he could hardly think it was a high-compression engine. The author's remarks evidently applied to a station away from a large town. It would not do to put a 20,000-H.P. gas-engine plant down in the middle of a town, as the noise would be too great; therefore if the author was going to generate power and transmit it a distance, it meant polyphase transmission, and he could not accept the author's argument that because one gas-engine ran in parallel with a number of steam-engines, that a number of gas-engines were going to run in parallel together on polyphase generators. The author seemed to think that there would be no difficulty whatever with parallel running. He would like to know if the author could mention any place in which gas-engines were running regularly in parallel without any assistance from steam-engines on alternating dynamos. He would further like to ask if

(Mr. W. C. Goodchild.)

there was any difference in the positive as compared with an induced scavenging arrangement. From what some of the speakers had said, he should have imagined there was a difference.

Mr. HUMPHREY said that, before replying to the various speakers who had taken part in the discussion, he felt it was necessary to make a few general remarks. In the first place his Paper dealt primarily with certain experiments in the use of a particular gas in gas-engines for the production of power. All the details relating to the gas and to the experiments had been presented in a scientific spirit, and he had no apology to make for not having written a historical preface mentioning all other known kinds of gas-producers. The Paper, as first submitted to the Council, contained no account of the Mond producer-plant, and this was added later at their special request. There were other well-known plants for the production of power-gas, and it would have been an easy matter for him to give facts and figures relating to them ; but he had two excellent reasons for not doing so. Firstly, the Paper had already exceeded the usual limits of length ; and secondly, if ever comparisons were better omitted, it was when the advantage was all on one side. Mond gas was so very much cheaper than any other producer-gas suitable for power purposes that he felt, if anything was to be said of other plants, it should come from the makers themselves who had every opportunity to attend the discussions or join in the correspondence.

With regard to Mr. Crossley's remarks (page 122) on the 400-H.P. gas-engine which his firm supplied to Messrs. Brunner, Mond and Co., he was equally certain with Mr. Crossley that the adoption of water-cooled pistons, higher compression, and some means of doing away with fluid losses would easily increase the thermal efficiency of the engine to 30 per cent. or over. The system described by Mr. Crossley of cutting off the gas- and air-mixture at variable portions of the stroke, according to the work to be done, should give good results, but he was afraid that the system had already been in actual use. Mr. C. E. Sargent had even gone one step further, and in starting his engine ignited at the cut-off point

and worked on the old Lenoir cycle, until sufficient speed was obtained. When he was in East Pittsburgh, U.S.A., in 1898, he asked one of the Westinghouse engineers why they did not adopt a sharp, variable cut-off on their gas-engine, instead of wire-drawing the mixture; and the reply was that steady running was considered more important than extreme economy; and by wire-drawing, the control of the governor was more immediate and sensitive, and simplicity of mechanism was obtained. Mr. Crossley mentioned the stepped die for gas admission. Having seen the arrangement at work on other gas-engines years ago, he mentioned the fact that it was not new, because anyone reading his reference to its use in the Paper might think it was of recent origin. Still he was glad to learn that it emanated, like so many other excellent inventions, from the Crossley family.

Mr. Crossley spoke highly of the small Mond plant now used for supplying the driving engines of his workshops with power-gas, but mentioned a small difficulty of renewing the sawdust in the scrubbers somewhat too often. As the Premier Co., who also worked a small plant, did not complain of any difficulty and Mr. Crossley expected to entirely get over the trouble, the subject was scarcely worth dwelling upon. It might be interesting to learn that for the last nine months the number of changes of sawdust in the scrubbers at Winnington power-house had been a collective total of seven; and as each meant the use of two bags of shavings and four bags of sawdust, the total material for filtering the gas amounted to 28 bags of sawdust and 14 of shavings. As two men could easily clean a scrubber and refill it in half a day, the cost of labour, sawdust, and bags of shavings amounted to 46s. for nine months, or at the rate of 4d. a day for a 1,000-H.P. plant working continuously.

A number of questions on the subject of the Crossley engines had been asked during the discussion, which showed that the following information would be of use. It took 2½ minutes to start the 400-H.P. gas-engine from rest, and to parallel it with the others. Compressed air at 60 lbs. per square inch was used in starting. The longest continuous run on load had been from 21st November 1900, until 17th January 1901, a period of 57 days, with but two stops,

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one of which occurred on 6th December, when a new circuit was coupled up, and the other a fortnight later when the commutator of the dynamo was ground up. The valves of the engine were last cleaned on 25th October 1900.

The balance sheet of heat quantities for the 400-H.P. Crossley engine was in round numbers :—

		Best results.
Heat converted into work (I.H.P.)	. . . .	27·8 per cent.
Heat lost in water jacket and exhaust valve	. .	24·2 ,,
Heat in exhaust gases and radiation losses .	. .	48·0 ,,
Heat in gas (higher calorific value)		100·0 per cent.

The low loss of heat in the water jacket should be remarked. The figures for heat losses in cooling water and exhaust gases given for the Cockerill engine were reversed in the case of the Crossley engine.

The balance sheet of heat quantities for the 500-H.P. " Premier " engine was even more striking, and the following were the figures of the most recent test :—

Heat converted into work (I.H.P.)		33·65 per cent.
Heat lost in cooling water—		
Cylinder jacket	19·28	
,, piston	4·94	
Exhaust valve	3·34	
Total loss in cooling water		27·56 ,,
Heat lost in exhaust gases and radiation . . .		38·79 ,,
Heat in gas (higher calorific value)		100·00 per cent.

These results were obtained when working the back cylinder only of the " Premier " engine, the gas being shut off the front cylinder. They were taken from the last two hours of a six hours' trial, and represented the best figures yet reached. It might be of interest to state that this was the 136th day of a continuous run of the smaller Crossley gas-engine referred to in the Paper, giving 90 to 100 H.P., there having been no stop for any purpose whatever since 25th September 1900.

Sir Frederick Bramwell (page 128) had for many years past pointed to a possible useful employment of gas as a medium for the transmission of energy, and had consistently held the view, even in the early years, when the gas-engine had its times of darkness and difficulty, that the internal-combustion engine had a great future. It was interesting to know that another great engineer, Sir William Siemens had, so long as thirty-five years ago, endeavoured to obtain permission to establish gas-generators at the coal pits for the distribution of cheap gas. Now it appeared such things were to be realised, and parliamentary powers were to be sought for the erection of gas-producers and the distribution of Mond gas in the South Staffordshire district, under conditions more advantageous than any which existed before the introduction of the Mond system.

Mr. Carr wished to know something about the tar (page 129), and the best proof he could give him that very little tar was made by the Mond system was this :—That the tubular regenerators through which the gas passed direct from the producer never required to be burnt out, as was done in other systems, and that any dirt collected from these pipes was in the form of a dry dust which would run through an ordinary cock like sand. Also the acid liquor, which met the gas before the final washing of the latter, might be expected to gather much tar by continuously circulating in contact with the gas ; but the quantity was so small that it was only sufficient to make the solid sulphate of ammonia, subsequently formed by evaporating the sulphate liquor, grey instead of pure white. The small quantity of tar separated from the washers, the regenerator towers, and the gas-mains, could not be said to possess any money value, although in a large Mond plant in the United States it was actually collected and distilled, and the pitch and heavy oil sold. On the question of ammonia recovery from towns' refuse, various experiments had been made, and Mr. Westinghouse had also written on the subject ; but he would remind Mr. Carr that the Paper dealt with the question of producer-gas for central stations, and for this purpose the use of towns' refuse could not be admitted. As to the quality of coal, Messrs. Brunner, Mond and Co. had about fifteen to twenty contracts running for the supply of different kinds of slack. It never happened,

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even for a single day, that one quality of slack was exclusively used at the producers.   However, speaking generally, the bulk of the slack used came from the Nottinghamshire and Lancashire districts, and the average analysis had already been given (page 73).   There were some slacks which, owing to their melting and caking into solid masses at low temperatures, were not so suitable for use in producers, as they needed the addition of mechanical apparatus, which it was better if possible to do without.

Referring to Mr. Dowson's remarks about the use of gas-holders (page 68), the sentence to which he referred was placed there to emphasize the fact that the supply of gas from Mond producers could be regulated automatically to be just equal to the demand.   Although gas-holders were not used at Winnington, cases might occur where they would be advantageous, and a small plant fitted with a gas-holder was illustrated (page 70).   Large mains did not act to any considerable extent as reservoirs of gas in the same sense that a holder was a reservoir.   As the pressure in the mains at Winnington did not usually vary $\frac{1}{4}$ inch of water-gauge, the capacity of the mains did not vary 1/1000 of their volume.   It was only the pipes near the engines in which the fluctuation was easily measured, and there the liberal use of gas-bags close to the engines was desirable.

Mr. Dowson raised the question of the presence of carbonic acid in Mond gas (page 131), and then suggested the correct answer by saying that "this was doubtless compensated for to a certain extent by the high percentage of hydrogen."   The facts proved that the compensation was not partial but complete, and constituted a sufficient justification for the Mond process looked at from that point of view; for even on the carbon basis the heat-units in the gas per kg. of carbon exceeded that with any other producer.   But other advantages of the system came out prominently, thus:—low temperature working and recovery of by-products would be impossible without the formation of CO_2 and hydrogen.   What really concerned engineers was the fact, that the ratio of the heat energy in the coal to the electrical or mechanical energy from the gas-engine was greater than for any other system; and going one step further, the fuel cost per brake or electrical H.P. was still more favourable, owing to the use of cheap coal.   It would

not come as any surprise when he said that a gas-engine worked much better and more smoothly with producer-gas than with lighting gas, and that it was possible to get as good a thermal efficiency with the one as with the other.   Dr. Mond even advocated the use of a still poorer gas ; and the method of putting back some of the exhaust gas from the gas-engine into the producer, and so reducing the calorific value per cubic foot while increasing the total volume, had led to very good results.   It was desirable to mention, at the risk of saying once again what was known to all who had studied the gas-engine, that a pure explosive mixture like methane and oxygen, even if it could be used in a gas-engine, would give but a very poor thermal efficiency.   Also to get good results with ordinary coal gas, the presence of inert gases, which took no part in the actual combustion, were necessary ; and it was only with a poor gas that the theoretical mixture for combustion could be approached.   The reason was found in the fact that certain chemical and physical causes limited the temperature which it was possible to reach in a gas-engine cylinder.   So long therefore as this limiting temperature was not lowered materially, a poor gas stood on as good a footing as a rich gas, and relatively large quantities of nitrogen and CO_2 could be present, without any loss in thermal efficiency and with a considerable gain in smoothness of working.   The increase in diameter in a gas-engine cylinder necessitated by the use of a poor gas was not considerable, and the cost of an engine to develop the same power with Mond gas instead of lighting gas was not a factor of great importance.   Mr. Dowson did not follow the idea that it would be desirable to work a small Mond plant without recovering the ammonia.   But surely it was clear that even without ammonia recovery the use of cheap bituminous coal still carried all its advantages, and rendered the fuel cost per H.P. very much lower than where anthracite or coke was used.   The information given in the Paper was not intended for the use of small consumers of electrical energy, but rather for engineers who had the designing of large power stations or for the owners of power plants.   Consequently he said nothing about the cost of electrical energy carried to the consumers' doors, but rested content with stating what could be done at the central station.

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Mr. Rollason was to be congratulated on his very clear statement (page 133) concerning the small Mond plant at Sandiacre. The results were quite new to the author, and formed a valuable addition to the discussion.

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Trial of 500-*H.P. Gas-Engine* (*Premier*)
working with Mond Gas,
Winnington Power House, 9th January 1901.

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Conditions.—Back cylinder only working, front cylinder running idle with gas shut off. Back cylinder working at maximum output with explosion every cycle. Cooling water supplied under a constant head to the jacket, piston, and exhaust valve of back cylinder, separately. By means of a swivel pipe the outlet water was diverted either to the drain or to a tank placed on a weighing-machine. The respective quantities of water were determined by repeated weighings, all of which agreed very closely.

The average figures were taken from the last two hours of a six hours' run :—

Average revolutions per minute .   .   .   .   .   127·4

Mean effective pressure, back cylinder   .   lbs. per sq. in.   107·05

I.H.P. of back cylinder   .   .   .   .   320·92

OUTPUT ON DYNAMO :—   Ampères   1,610

                               Volts   89·7

                               E.H.P.   193·57

Gas used, total as measured   .   .   cubic feet   32,060

Gas used per hour (0° C. and 760 mm.)   cubic feet   15,450

GAS ANALYSIS :—

     CO_2 Volume per cent.   .   .   .   14·8

     CO   ,,   ,,   .   .   .   11·7

     H   ,,   ,,   .   .   .   28·4

     CH_4 ,,   ,,   .   .   .   1·8

     N   ,,   ,,   .   .   .   43·3

                               100·0

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CALORIFIC VALUE OF THE GAS.

</div>

"Higher" calorfic value.		"Lower" calorific value.	
Kilo-calories per cubic mètre.	B.T.U. per cubic foot.	Kilo-calories per cubic mètre.	B.T.U. per cubic foot.
1,398·1	157·0	1,246·2	140·0

HEAT LOST IN COOLING WATER.

	Weight of water used per hour.		Average Temperatures.			Kilo-calories per hour, carried away.
	Lbs.	Kgs.	Inlet. C.°	Outlet. C.°	Rise. C.°	
Cylinder . .	5,194	2,356·6	3·30	53·35	50·05	117,947
Piston . . .	2,031	921·4	15·7	48·5	32·8	30,222
Exhaust Valve	1,052	477·3	15·0	57·8	42·8	20,428
Totals . . .	8,277	3,755·3				168,597

THERMAL EFFICIENCIES (Back cylinder only working).

	Gas consumed per hour At 0° C.		Kilo-calories consumed per hour.		Thermal Efficiencies (as per cent.) calculated on	
	Cb. Ft.	Cb. Mètres.	Higher.	Lower.	"Higher."	"Lower."
Per I.H.P Hour.	48·14	1·363	1,906·0	1,698·9	33·65	37·76
B.H.P. Hour.	71·83	2·034	2,843·7	2,534·8	22·56	25·30
E.H.P. Hour.	79·81	2·260	3,159·7	2,816·4	20·30	22·78

BALANCE SHEET OF HEAT QUANTITIES.

(Calculated on the "higher" calorific value of the gas.)

Heat converted into work, I.H.P.	.	.	.	.	33·65 per cent.
Heat lost in all cooling water .	.	.	.	.	27·56 ,,
Heat in exhaust gases and radiation losses		.	.	38·79 ,,
Total heat in gas used ("higher" value).	.	.	100·00 per cent.		

NOTE.—The electrical efficiency of the dynamo at part load has been taken as 90 per cent.

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Professor Burstall had added (page 135) some useful information, and in his remarks he made the statement that for ignition purposes it was quite immaterial whether the ratio of air to gas was 3 to 1 with a weak gas or 10 to 1 with a strong gas. His own opinion was that the presence of an excess of oxygen was more favourable to ignition than an excess of merely inert gases. If one added a quantity of hydrogen, for instance, to air, so that the heat-units per cubic foot of mixture amounted to a definite quality, and made another mixture with less air but more producer-gas (which of course introduced CO_2 and N), so that the mixture had again the same heat-units per cubic foot, then he had strong reason to think that the first mixture could be ignited more readily than the second. Professor Burstall might have some experimental results to prove his statement, and if so it would be very interesting if he would kindly place the Members in possession of them. He was usually right on such subjects, and his remarks on gas-engines were always helpful.

The remarks of Mr. Dixon (page 138) showed clearly that he had not appreciated the nature of the work which Dr. Mond had accomplished, and the importance of its success. He spoke as a student of the past when he said that among the many who deserved to be remembered in the future for work done on the subject of power-gas, two names would stand out with special lustre. One of the names was that of their member Mr. J. Emerson Dowson, and the other was that of Dr. Ludwig Mond. Mr. Dowson made it possible for a small gas-power plant to be worked more cheaply than a small steam-power plant; and his gas plants, using anthracite and coke, gave the impetus to the use of larger gas-engines than could have been economically used with lighting gas. Dr. Mond carried the question of the manufacture of power-gas into quite new regions, when he was able to employ cheap bituminous slack for the purpose; and this, coupled with the recovery of by-products in quantities previously thought impossible, advanced the question of fuel economy and still more of fuel cost, well ahead of any point to which the best steam-engines could hope to attain, and rendered the system adaptable to the very largest as well as to comparatively

small installations. Here again it was the Mond gas which made the demand for the large gas-engines, just as was the case on the Continent, where the use of blast-furnace gas created the demand for the large Cockerill, Otto Deutz, and Oechelhaeuser engines. Mr. Dixon would do well to confine the term "producer-gas" to its legitimate use; it was simply adding confusion to include blast-furnace gas in this term.

He did not need to go into the question of load-factors, because as soon as central stations produced energy at the cost figures already arrived at in the Winnington power house, load-factors of 33 per cent. and better might be expected. Some tramway stations in America had already passed the 33 per cent. stage, and even in ordinary lighting stations in this country the average load-factor was not so bad as Mr. Dixon would have them believe. He did not give the $0 \cdot 778d$. as the fuel figure for Case I to compare with Case IV, Fig. 24 (page 57), as Mr. Dixon asserted, but he gave a better figure for the steam-engine than the $0 \cdot 4d$. which Mr. Dixon mentioned for Liverpool and Manchester. He had been at some pains to show that alternators run by gas-engines could be put to work in parallel.

Mr. Dugald Clerk stated (page 141) that the nature of the real advance made by Dr. Mond was different to the advance claimed. But nowhere could he himself find any mention as to what that difference was, consequently he would dismiss the point. He would like to know what Mr. Clerk called a good producer-gas. Surely Mond gas having a calorific value of 150 B.T.U. per cubic foot was a good gas, if not where would Mr. Clerk find a better? Dr. Mond had therefore found the right conditions for making a good producer-gas and at the same time recovering the maximum quantity of ammonia, so that the two things could not be altogether antagonistic. Mr. Clerk also attacked the efficiency of the Mond producer, and referred, quite unnecessarily, to an earlier Paper of the author's, giving the extra fuel required for raising the steam added to the producer. Such figures were clearly stated in the present Paper (page 95). But Mr. Clerk's treatment of the subject, whereby he made the efficiency of the Mond producer appear as 67 per cent., was misleading for the following reasons :—

(Mr. Humphrey.)

(1) If he made a comparison with other producers which did not recover ammonia, he should take the corresponding case of the Mond plant working without recovery; then less steam, and consequently less extra fuel was required, the amount being less than the extra fuel used for the Dowson producer. (2) If he took the case of the Mond plant working with ammonia recovery, he should convert the money value of the net resulting gain from the by-products into its equivalent in slack, when he would find a substantial balance in hand above the extra slack used. On another matter he had to disagree with Mr. Clerk, for in considering the heat quantities it was quite as fair to take heat from the exhaust gas of a gas-engine and put it back into a producer, as it was to utilise the hot-well water for the feed of a boiler, or to use the boiler-flue gases in an economiser. The comparison was between producers and gas-engines on the one hand, and steam-boilers and steam-engines on the other; and all possible economies should be added in the first case, just as they were included in the second. It was so much the better for the gas plant that large economies were possible.

Turning now to the volume of gas from a ton of coal, it was clear beyond all contradiction that if the total carbon in the coal fed into the producer was known, and also the carbon lost in the ashes, dust and tar determined, the balance must be the carbon in the gas. The accuracy of the method resolved itself into a question of the proper organization of the sampling and analyses, and the care with which the tests were made. Such a method would be difficult to apply to a short test, but when the experiment extended over long periods as at Winnington, it became a reliable one, and he claimed accuracy for the results which were borne out by actual gas measurements at the small plant at Sandiacre. It was of course unfair to mix up the figures from different experiments under different conditions recorded in two different Papers with a few years' interval between them; and before hazarding the assumption that the efficiency of the Mond plant was only 50 per cent., it would have been better for Mr. Clerk to have pointed out any inaccuracy in his figures, or to have consulted some one like Professor

Threlfall, who had spent a whole week at Winnington, and had taken the trouble to go fully into the matter. Mr. Clerk's criticism cast reflection upon the accuracy of the author's figures, as the result of his own " rather careful study " of the subject. This so-called careful study, however, turned out to be characterised by false assumptions and neglect to take important points into account. Professor William Robinson had been kind enough to go carefully through the figures, and, as he had already stated (page 164), had found them entirely consistent. Mr. Clerk was therefore at fault in his calculations regarding both the 50 per cent. efficiency and the lost hydrocarbons. He was again wrong when he spoke about the compression of the large Crossley engine being 60 lbs. The average for the two cylinders was much nearer 80 lbs. per square inch, as could at once be seen from the Paper (page 46). Also his remarks about the engine being so beautifully adjusted as just not to pre-ignite, etc., were shown to be without foundation, when it was stated that the engine was designed to give 100 lbs. compression and a correspondingly higher horse-power. Mr. Crossley had frankly given the chief reasons why it did not do so. He was afraid that Mr. Clerk was behind the times when he said (page 146) " no doubt the difficulties of water-jacketed pistons would be overcome." They were overcome three years ago. Finally Mr. Clerk advised them to go slowly. They were to shut their eyes to the fact that the problem had been solved, and to hang back lest they should find themselves abreast of their American cousins or ahead of their German friends, which would be at least something unusual.

As regards Mr. Atkinson's remarks about the relative merits of the two types of engines (page 148), he would leave that matter to the makers themselves. The three engines in the Winnington power-house were doing extremely well, and they were already contemplating the addition of several more.

Mr. HUMPHREY, in reply to the Discussion on 8th February, wrote that the valuable and comprehensive Tables (pages 154–161), which Mr. Bryan Donkin had prepared, formed an interesting

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résumé of the progress made in the thermal efficiency of internal-combustion engines during the ten years 1890 to 1900. Mr. Donkin referred to the curves given in Fig. 28 (page 63), and thought quite correctly that the zero of the I.H.P. and the zero of the gas consumed should correspond; but he had failed to notice that, for the sake of economising space, no ordinates of I.H.P. between zero and 50 I.H.P. were shown. If the curves had been continued beyond the diagram they would have passed through the zero all right. Mr. Donkin also asked about the price of gas, namely 2*d*. for 1,000 cubic feet charged to the Northwich Electric Supply Co. This company started with one 100 H.P. gas-engine and had increased to three 100 H.P. gas-engines, so that the supply station was still small although growing rapidly. The price of 2*d*. per 1,000 cubic feet was therefore the charge to a rather small consumer.

The wording of the statement that 84·1 per cent. was " the calorific value of the total gas made as a percentage on the calorific value of the total fuel gasified " should not admit of ambiguity, and any coal burnt under boilers for raising steam was clearly not included. Even if Mr. Donkin and other speakers had had any doubt on this point it should have been removed by the statement made (page 95) as follows :—" If exhaust steam is not available for use in the Mond producers and live steam has to be raised in steam boilers, then 20 to 25 per cent. should be added to the amount and cost of the fuel." It was only when working the ammonia recovery plant that this quantity of extra fuel was needed. One or two other questions put by Mr. Donkin related to small Mond plants used for gas-engines. No producer could entirely stop making gas at a moment's notice, as a small quantity of gas due to slow distillation would be formed after the blast was shut off ; but where there was a holder, as in all *small* plants working for power-gas only, the gas entering it was stored up ready for starting the engine next time. As to dust and dirt, there was of course a small quantity, but it was dealt with in the wet state and caused no nuisance or trouble. The blast-pressure of the air varied according to the gas-pressure required in the mains and the number of pipes and apparatus through

which the gas had to pass. The minimum pressure was somewhat under 12 inches of water.

Mr. Donkin thought it a pity that the author had multiplied lbs. by degrees Centigrade to express quantities of heat (page 74). If he sinned in this respect he did so in excellent company, for he noticed that in some of the best and most recent scientific publications the "pound-degree Centigrade" heat-unit was freely used. Was it not better that all engineers should assist in introducing the Centigrade scale, and so hasten the time when the system of units in this country should be more rational than at present? If the lb. could be exchanged for the kilogramme at the same time all the better, but that was not likely to come so soon. He fully agreed with Mr. Donkin as to the desirability of settling, once for all, the question as to whether the "higher" or "lower" heating value of a gaseous fuel should be adopted as the basis upon which the thermal efficiency of a gas-engine should be calculated, and trusted his suggestion on this matter would be acted upon.

Professor William Robinson had, in his long and varied experience with gas-engines, observed some drawbacks to the ordinary non-scavenging Otto cycle, from which however the small non-scavenging engines at Winnington seemed singularly free. It was true that a "governor" card was always larger than a "following" card, but no falling off in power had been observed in these particular engines even after weeks of continuous work, and no regulation of the gas valve was required. Of course these engines were comparatively small, and Professor Robinson's remarks applied to larger cylinders, and then water-jacketed pistons became imperative, or all the evils he pointed out would be only too obvious.

Mr. Crossley was quite right in looking after the interests of his firm; and he himself was glad to say that the final form of Table 1, Appendix V (page 81), would give the thermal efficiencies calculated on both the higher and lower calorific values of the gas. It was only after the Paper was written he learnt that the Gas-Engine Research Committee had adopted the "lower" value. Consequently in adding the "Premier" results he used *both* values, so that members could still make a direct comparison between the

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two sets of figures. Mr. Crossley had, quite unintentionally he was sure, made it appear as if one engine was favoured by the manner of stating the results.

Mr. Ellington took exception to his deducting from the cost of the coal the value of the sulphate of ammonia recovered (page 173). As the ratio of the quantity of coal bought to the quantity of sulphate sold was a fixed one, it was simpler to deal with the two quantities together in the calculations. How Mr. Ellington would have treated the matter he did not know, as he had followed the course which appeared to him to be dictated by both the scientific and common-sense aspects of the case. In converting slack into power-gas at a central electric station, no one would think of going to the extra expense of adding an ammonia recovery plant, unless with the object of reducing the final cost of the gas. If the slack used was low enough in price, the profit made by recovering the ammonia might more than cover the cost of the fuel, but this did not make the value of the slack a negative quantity. Both the slack and the sulphate of ammonia had definite market values which had been used in his calculations; the value of the slack depended a good deal on the locality. Mr. Ellington would like him to double the coal cost per kilowatt-hour at Winnington, as given in the diagram, Fig. 24 (page 57); but the notes on the diagram (page 95) explained that the fuel cost figure was not an assumed but an *actual* one, and would be still lower if full credit was allowed for the ammonia recovered. Then again, the figure he used, namely 12s. per ton, in dealing with the coal costs at ordinary electric-light stations was if anything below the average for the central stations in this country for the year 1898. In Appendix IX (page 93), he gave a set of figures for a gas-power central station, in which the price of common slack for use in Mond producers was taken to vary from 3s. to 10s. per ton, but he did not see why this made his figures difficult to follow. In a coal-producing district the ratio of the prices of "coal" and "slack" was not the ratio of their respective calorific values, the slack being relatively much cheaper. In dealing with the gas-power station he had taken the fuel used per unit as constant. This was not so wrong as Mr.

Ellington appeared to think, and therein lay one of the differences between a steam plant and a gas plant.   With a 33 per cent. load factor the fuel consumption per unit was practically the same as for 100 per cent. load factor.   The stand-by losses of the gas plant were very small indeed, and the engine units actually at work at any time would be running at nearly full output.   If he made any difference it would be to reduce the fuel cost for the continuous full output, as the figure given was a very liberal one for the 33 per cent. case. Mr. Ellington's figures for the Wapping hydraulic station were remarkably good, much better in fact than those for any electric-light station in Great Britain.   But when Mr. Ellington said that in London rates amounted to more than the coal, and capital charges amounted to two or three times the station cost, he was taking extreme and not representative cases.   Indeed, even among the Metropolitan stations he himself could not find, in the Board of Trade returns, a single instance where the rates exceeded the coal cost.   The averages for all the Metropolitan stations were as follows for the year 1899 :— Cost of coal and other fuel per unit, $0 \cdot 94d.$; rents, rates, and taxes per unit, $0 \cdot 23d.$[*]   The published returns for the year 1899 showed that for the 118 electric-supply undertakings in Great Britain the generating or " works' cost " were over 60 per cent. of the " total costs."

He regretted he could not deal with Mr. Ewing Matheson's questions (page 176) in the way he would like.   His object was not to draw comparisons, but to state all the facts about the performances of the Crossley and " Premier " engines, and he must leave members to draw their own conclusions.   Mr. Hamilton's remarks were in the nature of explanations regarding the construction and working of the " Premier " engine, and called for no reply.

Some years ago he had seen the plant described by Mr. Goodchild (page 184), in which the Midland Railway had some 250 H.P. of gas-engines using Dowson gas, and noted with pleasure that the plant had been increased to 400 H.P.   The interesting figures of anthracite used and cost of fuel per unit were in strong

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contrast to the more economical results obtained at Sandiacre with the small Mond plant. Mr. Goodchild asked about the compression of the 150 I.H.P. Crossley engine at Winnington. It happened to be almost identical with the 85 lbs. now used in the engines at Leicester, but he had found no trouble from pre-ignition, and at the time of writing the engine had broken all previous records, by making a continuous run of six months' duration without one single stoppage and working at practically full load all the time. The question of the practicability of running a large central gas-engine station in a town could not be discussed in a few sentences, but he believed a properly designed station would cause no trouble. The chief points to be guarded against were vibration from the engines and noise from the exhaust. The products of combustion discharged from the gas-engine exhaust were of exactly the same nature as the flue-gases from an ordinary boiler, but the quantity was very much less for a given electrical output. In all probability the gas-producer plant would be kept outside the town, and the gas pumped through the gas-mains to the station. A 3-feet diameter main, even if several miles long, was of ample size for conveying the gas required for 20,000 H.P. of gas-engines. Mr. Goodchild doubted if gas-power dynamos could be paralleled for polyphase working, but at Oberhausen such working was in regular use, and was stated to give no trouble.

Communications.

(See Plates 10 and 11.)

Mr. J. WEMYSS ANDERSON wrote that he thought the Institution was much indebted to the author for the lucid and clear statements respecting the performances of large gas-engines, using what he had termed " power-gas." In the first place the expression " power-gas " appeared to be a very apt one, and he thought in future it might well displace all such expressions as " fuel gas," " producer gas,"

" Dowson gas," and " Mond gas," because after all one might as well speak of Belleville steam, Galloway steam, etc., in connection with steam-power.

The author dealt with the question of large power, as the title implied, and although the writer agreed with him in all the points that he argued in favour of large gas-engines and the Mond producer in particular, yet it must be remembered that large gas-engines were not likely to be used exclusively for the purpose of direct driving— such as a dynamo.   There could be no doubt that under such conditions the gas-engine was seen at its best, particularly where precautions of water cooling mentioned by the author had been adopted.   The gas-engine age was slowly but surely creeping on, and he was sure large firms could not do better than profit by the Paper, and, in substituting gas-engines for their steam-engines, they would be wise to have one generating-station in a convenient spot and transmit their power to the various departments electrically.   He would emphasise this point in contra-distinction to laying down a Mond gas-plant, and transmitting the gas to a number of gas-engines. His reason for emphasizing this point so strongly was, that an inquiry made three years ago into the working of gas-engines showed that the chief objections to gas-engines of about 100 H.P. and smaller (those of smaller sizes would of course be used if the power was distributed by gas-mains) were the great difficulties in the way of starting, and the troubles which arose from the belt which transmitted the power.   In laying down a plant at the Central Cold Stores in Liverpool, consisting of two 70-B.H.P. and one 20-B.H.P. gas-engines, the writer specified that no fast and loose pulleys were to be fitted, and selected the " Premier " positive scavenger engine.   A small starting-engine was used, and arrangements were made whereby the power required at the outset was exceedingly small ; and by this means the main belt could be kept in one position.   The results had in every way exceeded their expectations, and although as a rule only about 70 B.H.P. was in use, the consumption of fuel, including anthracite for the generator and coke for the small boiler, reduced to terms of anthracite, had given as the result of three trials a mean of 0·903 lb. per I.H.P. per hour.   The writer knew, however, of other

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plants of about the same size laid down at or about the same time, that had been replaced by steam, for no other reason than the difficulty experienced in starting, and the trouble and expenditure in belts. It was not, however, always convenient to take off the load from the gas-engine on starting, if belts were used, and hence his reason for protesting so strongly against the introduction of a number of small gas-engines where the total power was large. He thought that special thanks were due to the author for what might be regarded as startling facts, and for indicating the line along which the best results might be obtained.

Mr. ALFRED BACHE wrote to ask, in the absence of indication upon the drawings, whether any provision was made in the way of safety valves upon the large gas-main, as a precaution against injury by explosion. On the down-comer bringing off the gas from a blast-furnace, one or more flap-valves were placed on the upper side of the pipe, closing simply by their own weight ; on the occurrence of an explosion they were blown open, and presented such large vents for escape of pressure as to preserve the pipe itself from injury. Had there been any instances of explosion in the gas-mains of the Mond apparatus ? and if so, what had been the effect produced ?

Mr. ALFRED R. BELLAMY wrote that, with reference to the author's remarks on the designs of the large gas-engines working at Northwich, he would like to point out that his company, Messrs. J. E. H. Andrew and Co., of Reddish, were the first manufacturers in this country to make gas-engines with the cylinders facing each other, similar to Messrs. Crossley's design, the first engine of 50 I.H.P. having been made in the year 1887. They were also the first to construct a large gas-engine with tandem cylinders, having made an engine of 400 I.H.P. in the year 1893. A year previous to this the writer invented this particular design. His company could therefore claim to have had experience in both types of engines, and they at present made all double-cylinder engines similar to the early design, that is, with facing cylinders and crank-shaft between them. He quite agreed with what the author stated about the unsteady

turning-movement of this design, but the disadvantage of having two impulses in one revolution and none the next, as compared with one impulse every revolution was more theoretical than real. In the tandem design of gas-engine the weight of the reciprocating parts was a great disadvantage. He was of opinion that the point raised by Mr. Dowson with reference to the distribution of Mond gas was an important one. He would like to ask the author how he proposed to dispense with the use of gas-holders, where the load was intermittent but liable to be required suddenly.

Another important detail in the manufacture of the gas was briefly referred to by Mr. Crossley, namely the presence of tar in the gas. He considered it was imperative that the greatest precaution should be taken to get rid of the tar. His firm had experienced great trouble owing to tar getting into the engine cylinder, valves, etc. The author would oblige by saying how he was going to deal with this in plants which were not fitted with the recovery process. As a gas-engine maker he would like to say, that on the present "Otto" cycle the competition of gas-engines with heavy-power steam-engines was not likely to affect them seriously for some time to come. Until the world could be shown a successful rotary gas-engine of 500 H.P. without water-jacketed pistons and valves, they must be content to give the first place to steam as regards large power-engines.

Mr. J. EMERSON DOWSON, in continuation of his remarks at the meeting (page 130), wrote that he agreed with Mr. Bryan Donkin that it was desirable to know the heat efficiency of gas-engines. He went further, and thought that whenever possible the heat efficiencies of the gas plant, of the engine, and of the gas plant and engine combined should be given separately. It was however a more invidious task to institute an order of merit; and if this was attempted, it should be based on rigorous scientific tests made by independent experts, and not on the mere *ex parte* statements of the makers of gas plants or engines, or of members of their staff.

In the Tables prepared by Mr. Donkin (pages 154–161) there were several inaccuracies, and there were other reasons why the order of merit he had just put forward should not be accepted as correct.

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The final column of Table 1 (page 157) gave in large type the so-called " heat efficiency of engine per *brake* H.P. per cent. ; " but as a matter of fact several of the engines named had not been tried by brake at all, and at least some note to this effect should have appeared on the Table. He believed he was right in saying that there had been no brake trials of engines Nos. 1, 3, 4 and 6, and that their B.H.P. was merely estimated from the electrical work done. This would naturally involve questions as to the efficiency of the dynamos, the loss by belting, etc. ; and it was quite possible that if actual brake trials had been made, the results would not have accorded with Mr. Donkin's order of merit. Some of the engines were tested under full load, others under considerably less than full load. In some cases this was mentioned in the Table, but not in all. Neither the weight of coal, nor the volume of gas consumed per B.H.P. was given for No. 10 engine ; and without this its heat efficiency per B.H.P. could not be determined. No. 11 was not a suitable engine to compare with others which were in good working order and of more recent make. It was made in 1889, and was the first of its size, and the brake trials at the maker's works showed that the friction was so great that the engine was condemned. It never did real work as it was when tested in 1890, and it had to be altered considerably before it could be disposed of.

As to the so-called No. 12 engine, a strange mistake had been made. In Table 1 the power of this engine was said to have been 160·4 I.H.P. and 134 B.H.P.; but as a matter of fact these were the aggregate powers of *four* separate engines working together, each having only about *half its full load.* The details of the trials made of these engines were clearly set out in a report published by Professor Henry Robinson in October 1897. Each engine was specified to give 55 B.H.P., and to be on the safe side the makers supplied engines which could develop a maximum of about 60 B.H.P. each. In the first day's trial of five hours only two of these engines were working, and one gas-generator. The engines were driving dynamos with belting ; there were no brake trials. The total average power developed was 116·4 I.H.P., and from the current produced the engineer assumed that the average B.H.P. was 100·95.

At the writer's suggestion there had been a second day's trial of five hours, with four engines and two gas-generators, all working at about half their maximum power, so as to compare the fuel consumption of two engines fully loaded with that of four engines under light loads. The total average power in this second trial was 160·4 I.H.P., and the *assumed* B.H.P. was 134, and it was these aggregate results of four engines, working together under half loads (without a brake test), which Mr. Donkin gave in Table 1 (page 155) as the I.H.P. and B.H.P. of one engine. Moreover, he gave 156 B.T.U. as the lower heat value of the gas, whereas the actual tests made showed that this was the higher value at 16° C. From this mixed result he actually deduced in some unaccountable way the heat efficiency of some one engine! It reminded one of the famous trial in Alice in Wonderland, where the jury wrote down various dates on their slates, then added them up and reduced the answer to shillings and pence.

Regarding the heat values of the gas given in col. 18 of Table 1 (page 156), he presumed that all were based on the standard temperature and pressure, but it would have been well to have had a note to this effect on the Table. Some of the heat values in this column were given as higher and some as lower values; but surely the heat efficiencies of all the engines in this Table should be based on the higher or all on the lower heat values of the gas consumed. Some appeared to be based on the one, and some on the other; and, as Mr. Crossley pointed out, it was manifestly unfair to give an order of merit unless all the heat efficiencies were calculated on the same basis. Mr. Donkin remarked that the heat efficiencies of all gas-engines should be reckoned on the lower heat values of the gas, but he had not acted on this in preparing Table 1, and in Table 2 (page 160) he even queried the heat value of the gas in column 18, as though he did not know whether it were the higher or lower value. Notwithstanding this, he gave the heat efficiency of each engine working with this gas.

Apart from this, the question of treating as available, or not available, the latent heat of the steam produced on the oxidation of

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TABLE 1 (*continued on opposite page*).   *Trials of Engines and*

No. of Trial	Year.	Locality.	Name of Engine.	Maximum B.H.P.		Average Power during Trial.			Duration of Trial.
				Gas Plant.	Engine.	I.H.P.	B.H.P.	Elect. H.P.	Hours.
1	1881	Kensington	Crossley	6	·3½	4·41	3·26	—	5
2	1884	Openshaw	Crossley	30	30	32·6	27·5	—	5
3	1885	Rouen	Simplex	10	8	8·1	7·22	—	2
4	1886	Openshaw	Crossley	30	30	32·0	27	—	5
5	1887	Deutz	Otto	55	53	—	51·78	—	6
6	1888	Nürnberg	Otto	30	30	—	30	—	5⅙
7	1889	Schwabing	Otto	60	60	—	60	—	—
8	1890	Canale	Otto	40	50	—	36·45	—	8
9	1890	Rouen	Simplex	80	76	111·9	76·8	—	23½
10	1891	Uxbridge	Atkinson	20	16	16·7	—	—	6
11	1892	Chelsea	Crossley	150	150	118·7	—	—	8
12	1892	Longpont	Crossley	40	40	42·55	36·2*	25·29	5
13	1893	Montolieu	Crossley	20	18	20·16	15·22	—	—
14	1893	East Peckham	Stockport	40	40	50·2	40	—	12
15	1894	Sabadell	Crossley	120	{ 60 / 60	77·46 / 68·77	60·18) / 56·75)	—	5½
16	1895	Marlborough	Crossley	15	15	12·7	—	—	—
17	1895	Portadown	Stockport	70	70	73	—	—	55
18	1896	Halifax	Crossley	120	—	76	—	—	6
19	1897	Leyton	Premier	110	{ 60 / 60	116·4	100·95*	85·5	5
20	1897	Leyton	Premier	{ 110 / 85	{ 60 / 60 / 60 / 60	160·4	134*	107·6	5
21	1897	Carceres	Crossley	140	86	—	69*	—	3½
22	1898	Tees Side	Crossley	135	{ 60 / 60	120	102*	—	—
23	1898	Millwall	Crossley	250	{ 140 / 70	180·3	—	—	8
24	1899	Plymouth	Crossley	{ 70 / 70	120	139	117	—	—
25	1900	Gravesend	Stockport	{ 80 / 80	80	—	64·4	40·85	36
26	1900	Hamar	Crossley	62	70	63	51*	41·5	6

* Estimated from Electrical H.P.

Dowson Gas-Plants. (*concluded*) TABLE 1.

Kind of Fuel used.		Grammes of Fuel used per hour in Generator and Boiler.			Authority.	Work done by Engine.
Generator.	Boiler.	I.H.P.	B.H.P.	Elect. H.P.		
Anthracite	None	656	892	—	D. K. Clark.	Brake Test.
do.	Coke	543	613	—	J. E. Dowson.	Brake Test.
do.	do.	2244 litres of Gas	2518 litres of Gas	—	Prof. Witz.	Brake Test.
Gas Coke	Gas Coke	634	751	—	J. E. Dowson.	Brake Test.
Anthracite	Coke	—	764	—	Prof. Tieehmann and F. Böcking	Brake Test.
do.	do.	—	896	—	P. Beck.	Refrigerators in Brewery.
do.	do.	—	700	—	F. Uppenborn, for the Municipality.	Electric Lighting.
do.	do.	—	864	—	Dr. C. Monaco.	Flour Mill.
do.	do.	420	612	—	Prof. Witz.	Brake Test.†
do.	do.	483	—	—	J. Tomlinson.	Pumping Water.
do.	do.	345	—	—	J. E. Dowson.	Flour Mill.
do.	do.	546	612	917	J. and O. G. Pierson.	Electric Lighting.
Semi-bituminous	do.	2160 litres of Gas	2862 litres of Gas	—	Prof. Witz.	Brake Test.
Anthracite	do.	421	525	—	Arnold and Sons	Flour Mill.
do.	do.	567	729	—	Prof. Witz.	Woollen Mill.
do.	do.	543	—	—	Fairbank & Son.	Pumping Water.
do.	do.	403*	—	—	Andrew and Co.	Weaving, etc.
do.	do.	457	—	—	Shepherd and Watney.	Electric Lighting and Motors.
do.	do.	438	506	597	Prof. H. Robinson	Electric Lighting.
do.	do.	475	568	708	Prof. H. Robinson	Electric Lighting.
do.	do.	—	569	—	Neville and Co.	Electric Lighting.
do.	Slack	339	403	—	W. E. Wood.	Machine Tools and Dynamo.
do.	Coke	430	—	—	Engineer of Vulcan Insurance Office.	Rope Machinery.
do.	do.	493	588	—	Prof. Perry, F.R.S.	Brake Test.
do.	do.	—	620*	—	Handcock and Dykes.	Electric Lighting.
do.	Anthracite	404	500	614	E. Toot.	Electric Lighting.

* Includes stand-by losses. † Engine condemned on account of excessive friction.

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TABLE 2.

Trials of Engines and Dowson Gas-Plants.

No. of Trial.	Heat Value of Fuel used in Engine per B.H.P. per hour Calories.	Cubic Mètres Gas produced at 0°C. 760 mm. per Kg. Fuel consumed.	Heat Value of Gas produced in Calories per Cubic Mètre.	Heat Efficiency of Gas-Plant per cent.	Mechanical Efficiency of Engine per cent.	Heat Efficiency of Engine per B.H.P. per cent.
1	—	4·49	—	—	74	—
2	—	4·56	—	—	81·3	—
3	—	—	1,350	—	80	18·9
7	—	4·3	1,420	81·1	—	15
8	6,450	4·01	1,360	73·8	—	13·5
15	5,960	4·78	1,381	80·7	{78 82}	—
20	—	—	1,470	—	—	—
23	—	4·37	1,450	80·6	—	—
25	—	—	1,480	—	—	—

the hydrogen in the gas was an important one. Some engineers contended that this latent heat was not available for the purposes of an engine, and they deducted it when calculating the heat efficiency. It might suit them to do so, but it was not strictly correct. In the first place, they had to consider the heat efficiency of the gas plant, and to do this their balance sheet should show on the one side all the heat-units in the solid fuel consumed, and on the other side the total heat-units the gas derived from it was capable of yielding, when burnt to the best advantage. When the hydrogen in the gas was burnt, steam was produced, and the latent heat of this steam was available for heating purposes. The latent heat of the steam should therefore have been included in the heat-units derivable from combustion of the gas, and these heat-units should have been accounted for in the engine. It happened that in the gas-engine of today the exhaust products left at a high temperature, so that the steam formed on combustion of the hydrogen in the cylinder was not condensed; but if there had been complete expansion this would not have been the case. The present loss of the latent heat of the steam was due entirely to the engine, and should therefore have been debited to the engine, and not to the process of making the gas. The author had adopted the higher heat-value for the Mond gas, but in Mr. Donkin's Table 1 the lower heat-value was taken for the engines working with this gas; and the writer submitted that the higher value should have been taken throughout, or how could they correctly determine the combined heat efficiency of the gas-plant and engine? The writer had the records of twenty-six tests made with engines working with his own gas-plants, and although some of them were incomplete, he had tabulated such results as has been obtained in the accompanying Tables 1 and 2 (pages 208–210). In all cases he had given the names of the experimenters, and where any results were estimated and not determined by actual trial he had added a note to that effect.

As regards fluctuations in the quality of generator-gas, referred to by Professor William Robinson (page 166), his own experience was that with the larger sizes of plant the fluctuations were of no consequence in practical work. A little more care was needed in

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the working of generators of 50 H.P. and under, as the body of fire
was small and was more susceptible of change. In 1897 he had
made tests of the quality of gas in a generator of 110 B.H.P.
maximum while working at 90 per cent. of its full power, under
usual conditions. From noon to 5 p.m. the average calorific power
of the gas was 1,440 calories per cubic mètre at 0° C. and 760 mm.;
the maximum observed was 1,470, and the minimum 1,400. This
showed a maximum variation of less than 3 per cent. from the mean
value, and of only 5 per cent. between the highest and lowest values.

Professor H. HUBERT, of Liège University, wrote that he had
read the Paper with the greatest interest, and he thanked the author
for recording the experiments and tests which he, the writer, had made
in March 1900, with a 600-H.P. gas-engine working with blast-
furnace gas on the Delamare-Deboutteville and Cockerill system.
He was very glad to learn the success attained by Dr. Mond's
method of producing gas, which had solved practically a problem
of which he had recognised for a long time the importance to his
fellow-countrymen. He considered its discovery of the greatest
importance to industries, notably in coal-producing countries.

The organising committee of the Brussels Exposition in 1897
had decided to invite the exhibitors to state what they considered the
most important *desiderata* in each industry; and Commissions were
appointed to report on the question. Having been asked to assist,
the writer proposed the following question :—" To construct a gas-
producer for utilising bituminous and semi-bituminous coal gas as
obtained from the Belgian mines, for the economical production of gas
intended for feeding gas-engines." Although a prize of 1,500 francs
was offered for the solution of this question, no one came forward in
response. It was moreover deemed impossible of attainment, or at
least extremely difficult by the majority of engineers, considering the
difficulties that had already been met with in the construction and
working of a good gas-producer using coke or anthracite coal. The
latter fuel, which might be successfully utilised for the producing of
poor gas, was scarce and costly. It was not to be found in any large
extent in many of the coal basins. The writer knew an instance

where the question of the utilisation of gas-engines for a central station, previous to transforming the tramways of a town in Belgium, had to be abandoned in consequence of the difficulty in obtaining the necessary coal in sufficient quantities and at a reasonable price. The gas-plant brought out by Dr. Mond would satisfy this urgent demand, and it came at a time when sufficient progress had been made in the construction of gas-engines of large power. The Cockerill Co. and M. Delamare-Deboutteville had successfully proved that it was possible to construct a gas-engine having a single cylinder developing up to 700-B.H.P. Criticism had been passed on that point, and it had been claimed that it was an economic error, because a much greater regularity was obtained at less expense by means of four-cylinder engines.

No one would maintain that the single-cylinder four-cycle engine was very regular. But one could couple several units and derive the same advantages of regularity. The combination of four motors having alternate cycles on the Delamare-Deboutteville system would produce a regular motor whose useful work would amount to 3,000-H.P., and whose fly-wheel could be replaced by a dynamo.

In the special case of the gas-engine, which had been tested on 20th and 21st March, and referred to by the author, he might have mentioned the construction of a blowing-engine presenting the same advantages of simplicity as a steam-blowing-engine. In this case the question of regularity was not so important, and one might say that the Delamare-Deboutteville engine had absolutely answered the expectations of engineers. The great installation of the Société de Differdange (Luxembourg) would show the practical value of this solution of the utilisation of blast-furnace gas.

For those who had only a single blast-furnace, the firing and the behaviour of this plant during working rendered it useless as a gas-producer. Here again Dr. Mond's plant, which could develop considerable power, could be suitably applied and would remove an important objection to the use of gas in the blowing-engine.

In Belgium, where coal-mines producing coking-coal and inferior coal prevailed, and where they were generally surrounded by numerous works of every description, the application of Dr. Mond's

(Professor H. Hubert.)

invention would bring about an economic revolution. The time would come perhaps when coal-mines, instead of sending forth coal, would transform it into gas and distribute it to central stations for generating electric power in the district. The question had already been considered by the outlying districts of the town of Liège, which formed a very compact industrial group, in the midst of which were numerous collieries, some even situated in the town itself, and others in the vicinity of the manufactories.

In the large installations of gas-engines using blast-furnace gas it had been found necessary to produce the gas under pressure, because the simultaneous admission to several engines, from pipes of even large size, caused a relative vacuum. This caused the weight of the gas admitted to diminish during the stroke of the piston, and had, moreover, the inconvenience of inducing air to enter at the joints which were not always perfect, of the pipes and of the washing apparatus. This air would be likely at certain moments to cause an explosive mixture. Therefore they agreed to place between the blast-furnaces and the engines an exhausting apparatus furnishing gas to the engines at a certain pressure. It was probable that this remark would be equally applicable to installations of multiple engines and power-gas on the Mond system.

Mr. GEORGE H. HUGHES wrote that the subject of ignition was referred to by Professor Burstall and others, and he would like to ascertain if there was any trouble or misfires with the large engines under the author's supervision. A more positive means of igniting the charge had occurred to the writer, which was secured by injecting into the charge a jet of air and gas, or gas at a superior pressure to that of the charge, in close proximity to the electric spark or tube, or through the tube, so as to carry the flame right into the heart of the charge at the right time.

Mr. C. FREWEN JENKIN wrote that the author gave 84 per cent. as the proportion of the heat in the coal which was retained in the gas, and that this figure had been referred to in the discussion as the efficiency of the Mond producer. The author called the

corresponding figure in his Paper, read before the Institution of Civil Engineers in 1897, the "efficiency." As a matter of fact, these figures were not the efficiencies, because no account had been taken in them of the heat added to the producer by the steam. The amount of this heat was given as 13 per cent. in his former Paper, and if allowance was made for this, the efficiency was reduced to 74 per cent. This was somewhat disappointing, considering the elaborate air-jackets and regenerative appliances used, and seemed to indicate that some efficiency had been sacrificed to the ammonia recovery. The best efficiency for an ordinary type of producer was given by Åkerman as 75 per cent., which was found at Avesta.

He thought that rather more was claimed for the quality of the gas than seemed quite justified. The calorific power of the gas was given as 1,414 calories per cubic mètre (page 74). Åkerman found in the Avesta producer a calorific power of 1,549, which was a decidedly better result. This fact also seemed to indicate that some advantage had been sacrificed to the ammonia recovery.

Mr. JOHN JOHNSTON wrote that he thought the author was not justified in assuming that the two problems of producing power-gas from anthracite and from bituminous coal had been solved by Mr. Dowson and by Dr. Mond respectively. The problem of producing a good clean gas from bituminous coal was not solved, and would not be until it could be done on a smaller scale, as was done with anthracite in the Dowson producer. He did not say it could not be done on the Mond system, but it had not yet been proved that it could be done, and until this was so the problem was not solved. If Dr. Mond could place on the market a simple small producer to work with cheap bituminous coal, he would simply create a revolution in the use of the gas-engine for all power purposes. The production of power-gas, however, was one of those things more easily accomplished on a large than a small scale. The opposite, however, was the case with the engines, as the discussion had already sufficiently proved. The writer thought that the limit in point of size had been nearly reached with the "Otto" cycle explosion engine, and if further progress was to be made, there

(Mr. John Johnston.)

would require a reversion to earlier ideas and models with the " Otto " cut-out for small powers. Comparing the dimensions of parts of large power-gas engines and steam-engines of the same power, the gas-engine parts seemed massive beyond all comparison ; in fact, the shafts of the latest 1,000-H.P. gas-engines reached the dimensions of the shafts of ocean liners giving thousands of horse-power to gas-engines' hundreds.

With regard to the question of ignition of the charge in gas-engines, the two best methods he had found from experience were the small horizontal porcelain tube fixed at one end and closed at the other, and a low-tension electric spark induced by a small dynamo with permanent field-magnets and oscillating armature. Of the two, he thought the electric spark was the better. The porcelain tube fixed as stated gave no trouble in keeping tight at the joints, and it fired the mixture much sharper and through a greater variation of proportions than any metal tube would do. The point of explosion was also much more easily timed and maintained with the porcelain tube than with the metal tube, the timing being done simply by proportioning the passage between the tube and the combustion chamber. The writer had only once used a timing-valve, and found it to be more trouble than it was worth. He was also convinced that the horizontal position of the tube formed a considerable factor in the result obtained, because the bore of the tube and the passage leading to the combustion chamber formed one straight and unobstructed passage. The first result when the gases were ignited on the inner surface of the tube was to shoot a flame at considerable velocity through the straight passage into the middle of the mixture, ensuring the instantaneous ignition of the whole charge ; and this happened even with a weak charge that otherwise would have only burned locally. The Daimler Co. had found this action beneficial even in their small motors, for they constructed a chamber at the base of the ignition tube with a small passage leading into the combustion space ; the mixture in the small chamber was thus fired first, and shot a stream of flame out through the small passage into the heart of the mixture, ensuring its speedy ignition. If therefore this action was valuable on a small motor, how much more so must it be on a

large one, where the volume of gases was so much greater, and consequently more difficult to ignite? He considered if some such method were used on large engines, the result would be a great improvement in their working and fewer complaints of back-firing. The low-tension electric spark he considered the ideal method of ignition ; on the last engine for which he designed such an apparatus, the current was generated by a dynamo with permanent magnets and oscillating armature, and the armature was pulled round through its arc of revolution by a cam on the valve shaft, and then released when it was at the extremity of its travel. It was then pulled sharply back into its central position by a spring, and at the moment the armature was cutting the lines of force, a mechanical contact was broken in the cylinder, thus generating a large flaming spark. With an engine running at 180 revolutions per minute, the armature was let go twenty degrees from the back centre ; firing at this point the explosion line on the indicator diagram was only just inclining forward from the vertical, and this position was maintained through a large variety of mixtures.

The diagrams as the mixture was weakened became more rounded at the top, and the expansion line fell gradually until it was only one-third the original height, and then the engine began to misfire, but the lower part of the explosion line maintained its vertical position all through.

Mr. G. CECIL JONES remarked that the calculated numbers in Appendix I, Table 1 (page 73), many of which were carried out to the fifth significant figure, were based on a " typical " gas analysis, stated in round numbers only, and presumably not claiming accuracy beyond the second digit. In the same Table it was stated that the ashes from the producer had the composition : 87 ash, 13 carbon. This represented a loss of carbon equivalent to 1·56 kilogramme per 100 kilogrammes of slack supplied to the producer. The author deducted not 1·56 but 5·31 for " carbon lost with ashes, etc.," and perhaps he would explain whether the difference between these numbers represented a deduction he had made for loss of carbon with tar. Some tar certainly left the producer undecomposed ; tar

(Mr. G. Cecil Jones.)

settling tanks were shown in Fig. 23 (page 55), and it would be interesting to know the amount collected per ton of fuel used.

The author put forward a number, 84·1, which he correctly enough called the " calorific value of total gas made as a percentage on the calorific value of the total fuel gasified " ; but many readers would interpret this as the efficiency of the producer, and the author had on a former occasion * frankly called this ratio the " cold-gas efficiency." This was entirely misleading, since no account was taken of the large amount of steam supplied to the producer, apart from that generated in the air-heating tower. At Winnington there might be large volumes of otherwise valueless steam available, but this would not be the case in a central station. The author had practically admitted this in the Paper * before referred to, but the balance sheet in which he made allowance for heat added in exhaust-steam was in other respects inaccurate. This balance sheet, which was the only statement yet published which included all the data necessary to a correct estimation of the efficiency of a Mond producer-plant, was as follows :—

BALANCE SHEET FOR MOND PRODUCER-PLANT.

Total heat of 1 ton of fuel .	100·00	Heat of combustion of gas made	81·02
Heat added in exhaust-steam	13·43	Heat recovered in pipe regenerator	5·45
Heat (= work done in engines, &c.) . . .	0·29	Heat recovered in air-tower .	8·61
Heat (= steam condensed, &c.)	1·37	Heat remaining in gas (above 15° C.)	10·46
		Heat lost	9·55
	115·09		115·09

It had escaped criticism at the time of publication that the second and third items on the right-hand side of the account had no right at all to appear separately, being in fact already accounted for in the first

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* Proceedings, Institution of Civil Engineers, 1896-97, vol. cxxix, page 190.

item, 81·02. Had the heat, said to have been recovered, been applied
to some external purpose, instead of being used to heat up steam and
air on their way to the producer, the value 81·02 would have been
considerably lower; the items 5·45 and 8·61 should therefore have
been omitted, and the heat lost raised to 23·61.

In Appendix I, Table 2 (page 75), the author allowed
1·3338 kg. extra steam added per kilogramme of moist slack.
One kilogramme of *moist* slack had a calorific value of 6,202. The
added steam, if at 100° C., represented 830 calories supplied to the
producer, or 13·4 per cent. on the heat of one kilogramme of slack;
this agreed with the number 13·43 stated by the author in his
communication to the Institution of Civil Engineers. In practice
this steam would be raised in a boiler of perhaps 80 per cent.
efficiency, which meant the consumption of fuel equivalent to
1,037 calories. Allowing for condensation, as did the author in the
balance sheet referred to, heat equivalent to 1·37 per cent. on the
heat value of the slack consumed in the producer, further 85 calories
must be added, making a total of 1,122 calories supplied to a boiler.
Finally in the author's balance sheet was a figure 0·29 = " Heat =
work done in engines." As the combined efficiency of producer and
engine would be only about 16 per cent., this work would require
heat not less in amount than 1·8 per cent. on that of one
kilogramme of slack, or 112 calories. The true balance sheet for
a Mond producer-plant would then read :—

	Calories.		Calories.
1 kg. of moist slack	6,202	3·69 m.³ gas at 1,414 cal.	5,217
Heat supplied to boiler	1,122	Heat lost	2,219
Heat supplied to drive me-			
chanical washer, &c.	112		
	7,436		7,436

Efficiency : $\dfrac{5,217}{7,436} = 0.7016$, or 70·2 per cent.

In column 21 of the Tables put in by Mr. Donkin (page 157)
were given the heat efficiencies of various engines with generator
gas. It was unfortunate that these numbers appeared in heavy type

(Mr. G. Cecil Jones.)

in the final column, since many readers would suppose that here they had a set of numbers by which they could judge of the combined efficiency of various engines and gas-plants, whereas they had no relation whatever to the gas-plant, but represented the efficiency of the engine alone. It was also misleading to have the efficiency of the engine based on the lower, and that of the producer on the higher heat value of the gas; one or other must accept liability for the loss of the latent heat of the steam produced on combustion. The author's value, 1,414, used in calculating the efficiency of the producer was the higher value. In the first and best of Mr. Donkin's examples the efficiency of the engine based on this value would be 22·9 instead of 25·6. Combining this number with the efficiency of the Mond plant there resulted 22·9 × 0·702 = 16·1 per cent., which was the combined efficiency of a Mond producer-plant and "Premier" engine.

Professor E. MEYER, of Charlottenburg, Germany, thought that the further development of gas-engines driven with power-gas unquestionably depended upon the possibility of generating sufficiently clean power-gas from a cheap combustible in any given locality. In this respect the Paper was of great value, and its importance was enhanced by the satisfactory experimental data he obtained. It appeared, however, that the Mond gas-producer shown in Fig. 21 (page 52) was only suitable for very large plants. To appreciate the value of Mond gas for gas-engines in general, it would be interesting to know the smallest powers for which the producer shown in Fig. 21 would be available. For smaller work the Mond gas-plants were designed as shown in Fig. 35 (page 70). Here also he would like to know what was their lowest limit of power. Whether any plants were already at work, and what was the approximate heating value of the gas produced, because owing to the nitrogen in the exhaust-gases, this gas must contain a considerable amount of inert constituents.

The value of 84 per cent. given in Appendix I (page 74) as "the calorific value of total gas made as a percentage on the calorific value of the total fuel gasified" seemed to the writer too high, because

in calculating it the *higher* heating value of the gas generated was
taken as a basis.   But as only the *lower* heating value of the gas
came in question when utilised in a gas-engine, as shown in the
writer's paper " Experiments on Gas Engines," * this lower heating
value ought also to be used as a basis in making the above calculation
of the efficiency of the generator.   To complete their knowledge of
the utilisation of heat in the Mond gas-producer it would also be
desirable to take count of the heat consumption in the boilers to
generate steam for the blast.   He had drawn up such a complete
estimate of the transformations of heat in a producer in his Paper
" Experiments on the 160-H.P. power-gas plant with coke generators
at the Bâle Gas and Waterworks." †   In the appendices where the
coal used per H.P. was given, that used for the steam boiler should
also be stated.   Even if this were added, the figures obtained in the
trials would still be very favourable.

Herr MAX MÜNZEL of the Gas Motoren Fabrik, Deutz, Germany,
wrote that it was quite practicable to drive a 3-phase dynamo by
means of gas-engines running in " parallel," if the engine was
governed regularly on the usual 4-cycle system, without any missed
explosions, the gas during the suction-stroke being admitted more or
less according to the load the engine had to overcome.   The fly-wheel
should also assist the engine, so that the fluctuations of speed during
one revolution should not exceed a hundred and fiftieth or a two-
hundredth part of the normal.   The governor must follow the
slightest change in the load.   Electric ignition was of course the
only suitable arrangement under these conditions.   Tube ignition
did not give regular diagrams, and consequently the engine ran
irregularly, when changing from full to no load.

Diagrams, showing the very slight variations of speed per
revolution, had been taken by the writer from a 300-H.P. two-
cylinder, and a 600-H.P. four-cylinder engine, both at Gutehoff-
nungshütte, Oberhausen.   Two of the 300-H.P. engines had been worked

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* Zeitschrift des Vereines deutscher Ingenieure, 1896, page 350.

† *Ibid.*, 1896, page 1239.

(Herr Max Münzel.)

in parallel, and had conclusively proved that gas-engines, if properly
designed, were as suitable for such purposes as the best steam-engines.
The diagrams from the 600-H.P. gas-engine showed a greater
regularity than the 300-H.P. gas-engine. In the former the cylinders
were side by side, and there was an explosion at each revolution.

FIG. 46.—*Indicator Diagrams from* 1,200-*B.H.P. Gas-Engine* (*Deutz*),
using blast-furnace gas at Hoerde.

Revolutions = 135.
Diameter = 840 mm. (33 ins.).
Stroke = 1000 mm. (39·3 ins.).

From the indicator diagram, Fig. 46, of the 1,200-B.H.P. gas-engine
at Hoerde, Fig. 53, Plate 11, taken with a load of about 1,100
electrical H.P., it would be seen how regularly the curves covered
each other, and proved the efficiency and regularity of the electric
ignition per explosion stroke.

Mr. JAMES D. ROOTS wrote that he thought the Paper was
distinguished in the fact that it contained much information, new
matter, and new matter moreover of a very interesting description.
The diagram, Fig. 2 (page 47), was comparatively a new departure,
and one that it was to be hoped all gas-engine records published in
the future would imitate. He assumed that the ignition point
recorded at approximately one-twentieth of the stroke from the end
of the compression stroke was when the igniting valve opened, and
was not intended for the time at which the flame just struck into the
mass of the charge from the ignition port. He considered that it
would add to the value of the Paper, if the author would describe the
arrangement adopted of water-cooled piston.

The higher and yet higher compression the writer had persistently
advocated for many years past, the only limit to the degree of useful
compression being that at which the temperature resulting therefrom,
plus that received from the cylinder walls, was sufficient to ignite the

charge. If the degree of compression were such as to raise the temperature of the charge sufficiently to ignite it, then by passing the water through the jacket at a lower temperature to keep the cylinder walls cooler and to deprive the charge of some of the heat due to compression, the point of such ignition was roughly controlled and pre-ignition prevented.

It would be interesting to know the diameter of the valves in the engine of 26 inches diameter by 36 inches stroke. The writer gave some formulæ for determining the diameters and other dimensions of valves and their ports in an article recently.* Nothing of the kind had been published before, as far as he was aware, and he understood they had been useful to many engineers. But the formulæ were intended only to determine the valves, sizes, etc., for internal combustion engines of the cubic capacity of 12 inches diameter by 20 inches stroke and any engine of less than that size. It would be most interesting to know how near the results given by these formulæ were to engines of larger sizes.

In the Westinghouse gas-engine, he believed the charges were ignited by electricity. Now in using this ignition there was little or no difficulty in varying the degree or richness of the charge, and therefore the power of the working stroke, to effect the governing of the engines; but with tube ignition, even with alteration of timing of the ignition there were obvious difficulties, and many engineers would, he knew, be thankful to the author to elucidate this point. He noted that slack was reckoned at 5s. per ton, and the ammonia saving was valued at 4s. 6d. per ton of slack. Was this correct, as it would appear to make the net cost of the slack only 6d. per ton?

The engines considered in this Paper were of that class in which approximately 25 per cent. of the heat supplied to the engine was wasted in the exhaust, together with a pressure of 30 to 40 lbs. per square inch. Some of this lost heat and pressure should be utilised, and it was not very creditable to the dawn of the 20th century that they were not. The only way to effect a saving of a part of this waste heat and power was by compounding, using up as much of it

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* " The Engineer," 20th July 1900, page 49.

(Mr. James D. Roots.)

as possible in a second power stroke. The writer had given much
thought and attention to the subject of compounding in gas and other
internal combustion engines, and he was sure that economy lay in this
direction. He had watched, so far as he knew, all the suggestions
and designs published having this object, and he had not seen a
method so exceedingly likely to be effective as that shown in Fig. 47.
In this method of compounding in an internal combustion engine,
compression took place upon both sides of the piston H, but combustion
only upon one side B. The mixture of air and gas was drawn in
only at the back B of the piston H, where with one exception, the
usual "Otto" or "de Rochas" cycle was performed, that is, instead of the
used charge at the end of the combustion or working stroke passing
out of the cylinder and no further use being made of it, this charge

FIG. 47.   Section at *a b*.

by means of the port K passed to the other side of the piston. On
this or the front side of the piston air only was drawn in and
compressed. The valves for this side were arranged in a similar
way to those at the back, and as in an ordinary "Otto" cycle
engine. The flame and pressure from the back passed to the cold
compressed-air in the front by the port K, adding considerably to
the pressure by actual quantity and more so by raising the temperature
of the compressed air, the mixture thus producing a second working
stroke at a lower pressure certainly than the first, but at the cost of
one working stroke only. L L_1 were the exhaust ports, M M_1
were the inlet ports. Suction, compression, heating with the
consequent expansion, took place on both sides of the piston, but
ignition on one side only.

Mr. F. J. ROWAN wrote that, although it was not to be expected
that all the author's statements would pass unchallenged, yet there

could be no other than unanimous agreement as to the importance and interest of his Paper. Other important subjects would no doubt arise during the twentieth century, but few of more interest could meet engineers on its threshold. He shared the opinion that the comprehensive title of the Paper produced disappointment, as it raised expectations which were found to be not realised. Although the general subject of " Power-Gas and large Gas-Engines " was announced and emphasized by some remarks on page 43, in result the Paper was confined to the application of the gas-producer plant designed by Dr. Mond for large gas-engines, of which some good examples were mentioned. No notice was taken of other plans for making power-gas from coal or of the fact that the process differed only in degree from that employed with Dowson plant. He did not agree with the author in the first of his reasons for the delay in the adaptation of producer-gas to power purposes on a large scale, because gas-producers with cleansing appliances for the gas were able to supply clean gas made from slack coal (or " dross ") about the time when Dr. Mond turned his attention to the recovery of ammonia in paying quantity from the nitrogen of the coal used in producers, in which he followed on the lines previously indicated by Dr. Grouven of Leipzig, the late William Foster, Messrs. Young and Beilby and others.

The second reason given by the author on page 43, namely as to the development of the gas-engine, was sufficient in itself to account fully for the actual state of affairs in this industry. Until recently there had been no engine of large power made, capable of using producer-gas, the small gas-engines which had been made requiring the richer quality of illuminating gas. It was not difficult to understand how early attempts to use washed producer-gas in such engines had not been successful, especially when they remembered that the heat value of these gases was about four to one. It was the supply of waste gas from blast-furnaces, which led to the effort to make large gas-engines. With regard to the Paper as a whole, those who had studied the subject of gas-producers would hesitate to agree with the conclusion to which the author pointed, that the use of the Mond plant was the only, or even the best, solution

(Mr. F. J. Rowan.)

of the problem under discussion. In addition to the particular form of gas-producer used at Winnington several other plans were in use, and there was at any rate one system of economical production of the requisite quality of power-gas which was, from some points of view, preferable to that which was associated with the name of Dr. Mond. He referred to the producers and plant introduced by Mr. Duff, and applied in some large installations. The successful working of that plant at Fleetwood was beyond question, and he was informed that gas-producers and plant on this system, equal to the supply of suitable gas for engines of a total of 20,000 H.P. were under construction. That, it would be admitted, was a figure of great importance in connection with this subject. Moreover, Mr. Duff had also engines of 500 H.P.—in two engines of 250 H.P. each—working successfully with the washed gas from coke-ovens, and this was an interesting fact which might well have been accorded some notice in a Paper on this subject. From an engineering point of view, Mr. Duff's plant * had several excellent features in the arrangement of the method of combustion in the producers, in the recuperator or superheater, and in the general arrangement of towers and their connections—which were sure to have considerable influence on the economic results obtained.

Reverting to the Mond producers, from a fairly large practical experience of the working of Wilson gas-producers, which, after those of Tessié du Motay, had been perhaps the first to employ a cone-shaped retort in the upper portion of the producer, with the object aimed at by Dr. Mond, namely, the breaking up of the condensable hydro-carbons given off by distilling action from the coal, he was able to say that the realisation of the hoped-for retort action in gas-producers was almost wholly illusory. Tessié du Motay had used an iron cone similar to that of Dr. Mond, whilst in the Wilson producer the cone was formed of brickwork, which retained more heat, and was therefore more favourable to the action, and yet the presence of both tar and soot was undoubted in the resulting gas from Wilson

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* "The Iron and Coal Trades Review," and in "Engineering" of 11th January 1901.

producers. In fact these substances were at times deposited in the passages leading from the retort, even in the producer itself. The question of this retort, or " drop-curtain," had been raised in the discussion of Mr. Humphrey's Paper of 1897 at the Institution of Civil Engineers. The plan, adopted by Dr. Mond, of introducing the blast at the sides of the producer was also not so good as that of admitting the blast at the centre of the fuel, as it tended to the presence of more carbon dioxide in the resulting gas, because some air could escape upwards along the walls of the producer instead of all going through the fuel; and this uncombined air caused some of the carbon monoxide to burn in the producer.

With reference to the engines, there could be no question as to the economy in fuel consumption which was possible with gas-engines and producer-gas, as compared with the majority of steam-engines; and much credit was undoubtedly due to the ingenuity and perseverance of the makers of gas-engines, who had really been the means of bringing this subject into its present prosperous state. The advantages of gas over steam-engines for stationary purposes did not, however, stop there. Further great developments would certainly take place, and it could not be doubted that for central-station work the system of installing large gas-engines to work with producer-gas, which had been treated for recovery of ammonia, would in the near future entirely displace that of using steam-engines and boilers for the generation of electric energy. While this might be confidently expected, it was equally certain that increased experience in the construction and management of large gas-engines worked with " power-gas " would lead to better results being obtained and higher efficiencies in both gas-producing plant and gas-engines than those mentioned by the author. Amongst excellent results which had been obtained with gas-engines, one instance had been reported some years ago by Professor Ayrton, who had published the statement that a gas-engine of 50 H.P. using gas from a Dowson producer, developed power on a consumption equal to $1 \cdot 2$ lb. of coal per I.H.P. hour, which might be reduced to $0 \cdot 75$ lb. It was perhaps not easy to obtain at first so good a result from engines of large power, but

(Mr. F. J. Rowan.)

such should at least be striven for, and it would be fatal to accept
what had as yet been done as final success.

It must not be forgotten that steam-engines in the past had been
worked with a consumption of as low as $1 \cdot 01$ and $1 \cdot 2$ lb. of coal per
I.H.P. hour, as had been certified by the late Professor Macquorn
Rankine, in the case of engines and boilers made by the writer's
father, Mr. J. M. Rowan.   What had been done could be again
accomplished, and with possible improvements in the generation of
steam the limits of economy with steam-engines had not yet been
reached.   The writer had recently prepared a volume on the
" Practical Physics of the Modern Steam Boiler," * and if any of the
members would do him the honour of reading it, he thought they
would agree with him that there was still ample opportunity for an
improved steam-boiler, notwithstanding the hundreds of designs
which had been invented.   There was thus still an incentive to
gas-engine makers to improve on the good results already obtained,
especially as for central-station work there were advantages in first
cost, economy of labour, cheapness of fuel and return from residuals,
which must confer the superiority on the gas-engine system.

The author's figures of the efficiency of the Mond gas-producers had
already been dealt with.   With regard to those of the performance of
gas-engines with Mond gas which he gave, some corrections were
needed.   Taking the figure given in his Paper read to the Institution
of Civil Engineers, it appeared that the consumption of coal per I.H.P.-
hour had not been as good as he had represented it.   Mr. Humphrey
gave $1 \cdot 03$ lb. per I.H.P.-hour as the coal consumption, but also stated
that 3,051 cubic feet of gas per hour, as measured by meter, were used
by the engine, and that $38 \cdot 71$ I.H.P. were shown by the diagrams.
Taking these later figures, however, it appeared that the coal
consumption per I.H.P.-hour should be $1 \cdot 11$, $1 \cdot 75$, $1 \cdot 26$ or $1 \cdot 36$ lb.
according as they assumed 160,000, 150,000, 140,000, or 130,000
cubic feet of gas yielded per ton of the slack used.   If they assumed
160,000 cubic feet per ton, that was equal to 71 cubic feet per lb. of

* Published   by   Messrs. P. S. King   and   Son, Great   Smith   Street,
Westminster.

coal, and therefore the equivalent weight of coal represented by 3,051 cubic feet of gas was 43 lbs., which would show that $38 \cdot 71$ I.H.P. were obtained by means of a consumption of $1 \cdot 11$ lb. per I.H.P.

Similarly with the other assumptions :—

150,000, cu. ft. per ton = 67 cu. ft. per lb., or 3,051 cu. ft. = $45 \cdot 5$ lbs. coal.
140,000   ,,   ,,   = $62 \cdot 5$,,   ,,   = $48 \cdot 8$,,
130,000   ,,   ,,   = 58   ,,   ,,   = $52 \cdot 7$,,

Dividing each of these latter figures of lbs. coal, which were represented by 3,051 cubic feet of gas, by the I.H.P., the consumption per I.H.P. came out at the numbers given. In Appendix VI (page 87) the coal used per I.H.P.-hour was stated to have been $0 \cdot 92$ lb., which was correct only if 160,000 cubic feet of gas per ton of coal had been produced. If the other quantities named were produced, then the I.H.P.-hour consumption should be either $0 \cdot 98$, $1 \cdot 05$, or $1 \cdot 14$ lb. Until, however, the quantity of gas which was being yielded per ton of coal was accurately ascertained, it was evident that they could not be quite certain as to what was the actual consumption of coal per I.H.P.-hour in the case of an engine using producer-gas.

THE SWISS LOCOMOTIVE AND ENGINE Co., Winterthur, sent a description of the Dowson gas-plant, Figs. 48–50 (pages 230–1), at Embrach, in the neighbourhood of Winterthur, where a large factory of earthenware goods had lately been built. The motor plant had been erected in a separate building in order to avoid the destructive action of dust, which arose in all factories of this kind. The engine-house was divided in two parts, one for the gas-producing plant, the other for the engine.

The gas-producing plant consisted of three 200-H.P. generators, of which only two were at work, the third being kept in reserve. The generators stood side by side in a pit, so that all the feed-holes were at a convenient height above the floor, and easy of access ; for cleaning purposes and removal of clinkers it was necessary to go into the broad pit, where the inside of each generator

(The Swiss Locomotive and Engine Co.)

Electric Power-Station with Dowson Gas Plant.
Embrach, near Winterthur.

FIG. 48.

FIG. 49.

Scale, see plan.

could be inspected through two doors. Fitted to the generators were three corresponding horizontal air-heaters, below which the gas-coolers were fixed ; from the latter the gas passed into the two sawdust purifiers. The gas proceeded from the purifiers through two cylindrical scrubbers of 5 mètres length into the 50-cubic mètre gas-holder which stood outside the building ; the freezing of water

Electric Power-Station with Dowson Gas Plant. Embrach, near Winterthur.

FIG. 50.
General Plan

(The Swiss Locomotive and Engine Co.)

contained in it was prevented by means of a small boiler in which the water was heated.   The generators were arranged so as to allow the gas to pass through either one or other of the purifiers, or both at the same time.   The generators and scrubbers were of the usual type, and the sawdust purifier contained several plate shelves on which the sawdust was spread.   A series of doors were so arranged that the plate shelves could be taken out for the renewal of the sawdust.   The regulation of the gas production was effected in the usual manner, by connecting the steam-valve of the generator with the gas-holder cover.   The steam for all three generators was taken from a vertical tubular steam-boiler which had a heating surface of 10 square mètres, on the top of which was a serpentine superheater.   The boiler was fed by injectors and heated by means of briquettes and also of anthracite, which was obtained by passing the clinkers from the generators through sieves.

Three 100-H.P. and one 40-H.P. electric-generators were erected in the engine-room.   Each motor drove, by means of a belt from the fly-wheel, a three-phase generator, to which an exciter dynamo was directly coupled, and which furnished the working current for the machines in the factory.   The 100-H.P. motor ran at 160 revolutions per minute, and the three-phase generator at 500 revolutions per minute.   All three motors could work in parallel.   The 40-H.P. motor ran at 180 revolutions per minute, and was used for lighting the works and for charging a small battery of accumulators.   In order to ensure smooth running the fly-wheels were fixed close to the belt pulleys.   Space had been reserved in the engine-room for the erection of a fifth motor.   In one corner of the engine-room was an electric motor which drove an air compressor by means of a belt; the air was stored in a reservoir and used for starting the motors. The electromotor was a continuous-current motor, so that the compressor could be driven by the accumulator current when the machines were not working.   Next to the air compressor was the descent for reaching a pit, which ran along the whole length of the plant, and contained the compressed-air reservoir, the small gas-holders for each motor, the air-exhausting retorts, the blow-out pipes, the expansion joints and the water-pipes, all of which were so

arranged that they were easily accessible. The blow-out cups were erected in shafts outside the engine-house, each motor having its own blow-out pipe and cups. The pit was ventilated by special air-shafts which were carried outside the building, and were closed with adjustable windows; the whole space was lighted by fixed and portable electric lamps. Next to each machine were the stop valves for the gas-holder and for the cooling water. The gas-holder could also be shut off from the motor and from the gas-producing plant by means of two valves. The cooling water was pumped from a well into a reservoir inside the engine-house by means of a centrifugal pump, driven by a three-phase motor. The pump and motor were erected in a pit from which the water was raised to a height of 40 mètres. The cooling water when used was allowed to sink into the ground. The cooling jackets of the motors and water-piping could be easily emptied when necessary to prevent the water freezing in them.

Description of a 100-H.P. Gas-Engine, Winterthur, (Plate 10).— This engine ran at 160 revolutions per minute. The cast-steel wheel counterweights were fixed directly on the arms of the shaft, which was made of Martin steel, thereby eliminating the horizontal vibrations caused by the connecting-rod and piston, and thus allowing the dimensions of the foundation to be reduced to a minimum. The bed-plate had a total length of 3,930 mètres, and was cast in one piece with the cooling-jacket of the cylinder, in order to assure absolute solidity. The inside wall was made of special hard cast-iron, and was interchangeable. The adjustable shaft-bearings were made in four parts, which were lined with anti-friction metal, and were abundantly lubricated by means of a circulating pump. The oil which escaped from the connecting-rod and bearings accumulated in a small recess under the bed-plate. The piston was lubricated by a special pump, which was driven from an eccentric mounted on the valve-motion shaft. The admission and exhaust-valves were arranged on the head of the cylinder, which was cooled by an extra circulation of water. The valve-rods ran in phosphor-bronze sleeves, thereby preventing corrosion of the same. The

valve-chest was the most delicate part of ordinary motor construction, and its walls had been so constructed that a fracture was not to be feared, in spite of the great variation of inside and outside temperatures. The exhaust-valve was worked by a double lever and a cam fixed on the valve-rod shaft, which was driven by helicoidal wheels; this arrangement saved the wear of the wheels and effected an absolute silent and even running. The two regulating valves were double-seated, the first introducing the mixture, the latter the gas, and were directly influenced by the governor, which effected the shutting of the same according to the work required of the motor. Regulation was effected in the same way as a steam-engine with valve-motion. The diagrams of the 40-H.P. motor proved that the ignition and combustion of the different charges were effected solely by the regulator. In order to regulate the number of revolutions of two motors working side by side, a spring balance was fixed on the regulator support, allowing a variation of 10 per cent. The working action of the electro-magnetic apparatus of the usual type was so arranged as to allow, while running, the moment of ignition of the mixture to be varied; this was regulated by means of a hand-lever from 0° to 90° as required. This advantage was of great importance when starting, as a too-early explosion or a backward movement of the motor was completely avoided. The starting of the motor was effected in the usual manner by means of compressed air, which was stored in a reservoir supplied by an electric-driven pump. Long trials of the 40-H.P. motor have shown that the consumption of the same when fully loaded varied between 350 and 400 grammes of Belgian anthracite per brake horse-power per hour.

Fig. 52, Plate 11, showed a two-cylinder 200-H.P. motor at 180 revolutions, using lighting gas, which was at present being erected in Berne. The construction of the bed-plate allowed the number of driving-shaft bearings to be reduced to two. The automatic manner in which lubricant was forced on the crank-pins, was further shown in Fig. 54.

Fig. 54.

Oiling arrangement on 200 H.P. Gas-Engine (Winterthur).

Scale $\frac{1}{20}$th.

Professor RICHARD THRELFALL wrote that he would confine his remarks to two points. The care and accuracy with which the author's tests had been carried out would undoubtedly make this Paper, like the previous one,* a classical contribution to the subject of gas-power. The next generation would certainly begin to feel the pinch of increased scarcity of coal in this country as compared with favoured locations in America, and perhaps Australia and China; and even the present one would recognise that there was even now a competition with cheap water-powers.

Both in the present and in the previous Paper the author made statements as to the relation between the I.H.P. or E.H.P. of a gas-engine, and the coal gasified at the producer. He thought that,

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* Proceedings, Institution of Civil Engineers, 1896–97, vol. cxxix. page 190.

(Professor Richard Threlfall.)

though these figures were probably sufficiently correct to enable estimates to be made, they nevertheless stood on a much lower plane of experimental certainty than the figures connecting the power developed in the engine with the volume of gas used. In the latter case it was possible to calibrate a gas-meter, and by observing caution to use a meter so calibrated in measuring a gas-supply, no doubt with sufficient accuracy. Also if they had a gas-producer working on such a scale that *all* the gas produced could be passed through the meter, they could readily ascertain the relation between the volume of gas produced and the coal fed into the producer. At Winnington, however, as everybody knew, gas was produced in far too large quantities to make such a course of ascertainment in any way practicable; and therefore indirect methods had to be resorted to in order to connect the volume of gas produced with the coal gasified. In practice the only method employed was by way of chemical analysis. The coal had to be sampled and fed into the producer in weighed quantities, the ashes, tar, and dust had also to be weighed, sampled, and analysed : finally, the gas had to be analysed, and the weight of carbon per unit of volume thus ascertained. Now by making the assumption that there were no overlooked sources of loss of carbon, it was evident that the total gas generated per ton of coal could be calculated. He need hardly say that he was sure that these operations had been carried out at Winnington with all the accuracy that the method admitted, but nevertheless it was clear that the process was complex, and it was unchecked in any way. It was for this reason that he considered the numbers referring to the coal as less satisfactory than the other data given by the author. He might perhaps add that on one occasion he had made a very extended trial of a gas-producer, the volume of gas being both measured by observing a gas-holder and by carrying out the process of analysis above described. The result had showed a very great divergence between the two values so obtained, and what was worse, he had never succeeded in finding out where the error lay. No doubt this only proved that he had made a bad experiment, but it had convinced him that the investigation was not as easy as one would naturally suppose it to be.

The second point he wished to raise was in connection with the subject of the viscosity of gases, as affecting the designs of gas-engines. The author referred (page 45) to the large fluid-friction observed in the bottom loop diagrams of a large gas-engine. The same point was elaborated in the diagrams on page 49, from which it appeared that the curve of horse-power lost, as a function of the speed of revolution, was concave upwards. Now if he were right in supposing that in viscous flow the resistance was proportional to the speed, the curve should have been a straight line : that it was not so seemed to show that one of the following alternatives must be considered :—(1) The resistance with a given mode of fluid motion was not proportional to the velocity ; or (2) the mode of fluid motion was altered ; or (3) the viscosity of the gases was not constant. The latter alternative was the one to which he wished to draw attention. The pressure of the gases was throughout not very far from atmospheric, and under such circumstances the viscosity varied as the square of the absolute temperature. If the gases were heated up to about $540°$ C. absolute, $= 270°$ on the ordinary scale, which was not unlikely, the viscosity would be quadrupled. The curves certainly showed that, allowing for the change of speed from 100 to 150 revolutions per minute, the fluid resistance had increased in about the ratio of two to one. Adopting the viscosity theory to account for this, it was seen that the air and gas must be supposed to be heated up from say $20°$ C. to $140°$ C. during the inspiration, in consequence of the high temperature of the air and gas passages. The alternative that the mode of fluid motion was seriously changed during an increase of speed of from 100 to 150 revolutions per minute appeared to the writer to be unlikely, as the motion was probably fully turbulent from the lower value. No doubt many engineers would regard this as trivial, and considered as a factor in the economy of the whole plant it undoubtedly was so. There was an aspect of the effects of gaseous viscosity which, however, was certainly not trivial ; he referred to the difficulty experienced in getting a perfect mixture of the gas and air. It was by no means easy to mix even hydrogen and oxygen in the cold, and in the case of gas and air in a compression chamber at a temperature which

(Professor Richard Threlfall.)

could not be very far from say 550° C., the difficulty was increased
ninefold. The only remedy was to arrange the admission valves in
such a manner that the gas and air during admission were broken up
into thin streams which were sandwiched together, or to arrange for
a rapid succession of alternate puffs of air and gas through apertures
with sharp edges, so that vortex rings might be formed and driven
against a boundary where they might expand and so be mixed. The
latter was, he presumed, impracticable, but the former method
appeared to be adopted in the "Premier" engine, and he would not
be surprised to learn from Mr. Hamilton that this might have some
bearing on the (so far as his experience went) unprecedented
regularity of the diagrams which were obtained from it.

Mr. B. H. THWAITE wrote that the subject raised by the author
of the Paper, although in its comparative infancy, was one that
already bristled with interesting features. He desired to touch on
the chemical character of the gas most suitable for supplying large
power capacity gas-engines intended for driving polyphase electrical
machinery. His own experience had led him to arrive at the following
conclusion, in formulating an ideal character of gas for the purpose
defined:—First, that the combustible constituent of the gas should
be of such a character that its oxidation should not involve a thermal
loss by latent heat effects, such as did hydrogen or hydro-carbons,
a heat loss that could not be recovered except by absolute
recondensation to water. Second, the combustible constituent
should be such that under no normal conditions of physical
compression or influence of temperature would it be liable to
condense in the gas-engine cylinders or gas-mains as tar. Third,
the ideal combustible constituent was that which provided per unit
of addition or deduction, within the limits of variation, the least
percentage variation in the heat value of the gas.

In order to demonstrate the effect of the third qualification, the
variation of the quantity of the percentage content by weight of the
hydro-carbon gases compared with that of carbonic-oxide in producer-
gas was remarkable, as shown by the following figures. Taking the
heat-value of carbonic-oxide, ethelene, marsh-gas and hydrogen by

FIG. 55.

Diagram showing the effect of the addition of Hydro-carbons and Hydrogen on the calorific character of producer-gas; also that the calorific value of Hydrogen over CO is not of appreciable advantage when measured by volume.

(Mr. B. H. Thwaite.)

weight, and comparing them with the percentage ratio, with carbonic-oxide as zero, ethelene (C_2H_4) gave 393 per cent., marsh-gas (CH_4) 443 per cent., and hydrogen 1,333 per cent. It would be easily understood from these figures that the introduction of an addition of any of the constituents, other than CO, would mean a considerable fluctuation in the pressure applied to the piston. Fig. 55 (page 239) showed graphically the effects produced by the addition of the three gases named. The graphic diagram also showed that the calorific superiority by weight of hydrogen over carbon-monoxide was almost entirely destroyed by the volumetric lightness of the former. It would have added greatly to the value of the Paper if the author had produced analyses of the gas, taken at intervals of fifteen minutes, during a run of twelve hours, along with indicator diagrams taken at the time the gas samples were being collected. It was impossible to obtain a satisfactory uniformity of heat values in gas depending on either the ethelene, marsh-gas, or even hydrogen constituents. The hydrogen constituent was advisably admissible only as a means of increasing the inflammability of the gas. Hydro-carbons were not desirable constituents of gas intended for large power gas-engines.

The ideal power-gas for uniform and steady running was one containing as combustible volumetric per cent. units some 30 per cent. of CO, and 3 per cent. of hydrogen. The gas produced by Dr. Mond's apparatus should be useful for furnace-heating purposes, or when uniformity of heat value was of minor importance; but it was not by any means an ideal gas for thermodynamic purposes, whether burnt in a steam-boiler or in the cylinder of a gas-engine. Dr. Mond had evolved a process of gas-making that for chemical manufacturing purposes was perhaps all that could be desired. He had obtained a higher proportion of ammonia from the fuel than had hitherto been considered practically possible, and the gas from his apparatus could almost be considered a secondary or by-product. His perseverance and lavish expenditure in carrying out his investigations and experiments, during a period of life when most men retired from business cares and attendant worries, was an admirable object lesson, and one deserving of the highest appreciation.

In the production of the gas for three-phase alternator driving, the uniformity of the character of the gas should be of supreme importance, and the by-products obtainable should be subservient to the main object ; and the only thoroughly satisfactory process of gas-making that would permit this was one in which the fuel had either been preliminarily denuded of its hydro-carbons, or had been split up into carbon and free hydrogen, or had never contained them.

The author had collected a considerable amount of valuable information. He would doubtless in a future Paper remedy some obvious omissions and acknowledgments that leave the Paper, although most admirable in many respects, somewhat incomplete. Probably the Institution would have had a difficulty in finding a subject more thoroughly appropriate for consideration at the beginning of a new century than that which the author had had the good fortune to introduce to its notice.

Mr. HUMPHREY, in reply to the written communications, wrote that the term " power-gas " found favour with Mr. J. W. Anderson (page 202), but it could not be used to displace the names of distinct fuel gases. The parallel Mr. Anderson drew between gas from different producers and steam from different boilers did not hold. The value of a cubic foot of saturated steam at a given temperature was the same no matter in what boiler it had been raised ; but the calorific value of a fuel gas depended on the process of its production, and varied between very wide limits. For example, Siemens producer-gas had a calorific value of 135 B.Th.U. per cubic foot, while for Dellwik water-gas the figure was just double. The question as to whether it was best to employ dynamos driven by gas-engines in a large works and to distribute electric energy to the various departments, or to use a number of small gas-engines and distribute power-gas to them through pipe-mains, must be settled for each individual case. It depended so much on the nature of the work, the variation of the load, and the frequency of stoppages, that no hard and fast line could be laid down.

Mr. Alfred Bache enquired (page 204) if there were any safety valves upon the large gas-mains shown in the diagram of the Mond

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plant. Explosions were not feared in these mains, for as they were always under pressure no air could be drawn in to form an explosive mixture. Accordingly there were no safety valves provided, although the water-lute valves would, if required, answer the purpose of providing an escape.

The firm of Messrs. Andrew and Co. deserved much credit for the courage displayed when they built a 400-I.H.P. tandem cylinder gas-engine in 1893, and it was to be regretted that the history of this engine was such as to lead Mr. A. R. Bellamy to abandon a design which possessed many promising features (page 204). Mr. Bellamy asked a few questions which had been already dealt with in the discussion.

Mr. Dowson's written communication dealt almost exclusively with Mr. Bryan Donkin's Tables, so it scarcely came within his own province to reply to it. But one point of some importance was raised in trying to solve the somewhat vexed question as to the correct basis upon which to calculate the thermal efficiency. Mr. Dowson said (page 211) :—" It happened that in the gas-engine of today the exhaust products left at a high temperature, so that the steam formed on combustion of the hydrogen in the cylinder was not condensed ; but if there had been complete expansion this would not have been the case." If this statement was correct the question would be much simplified, but unfortunately it was not correct. Take for example Mond gas which contained a large amount (29 per cent. by volume) of hydrogen. On combustion with only the theoretical quantity of air the products contained 17 per cent. by volume of steam, and no portion of this quantity would be condensed until the temperature fell to 57° C., at which temperature the amount of water vapour present was sufficient to saturate the other products. It was not easy to conceive any kind of gas-engine which would discharge its exhaust at a lower temperature than 57° C., even if expansion was carried to atmospheric pressure. He desired to thank Mr. Dowson for the very full and interesting particulars he had given of gas-engine trials using Dowson gas (Tables 1 and 2, pages 208–210).

Professor Hubert's valuable remarks spoke for themselves and called for no reply. Replying to Mr. G. H. Hughes (page 214), no

serious trouble was experienced at Winnington due to misfires. The charge never failed to ignite, unless the spiral spring failed to force open the timing valve or the ignition tube was not kept hot enough, but both these things happened occasionally. As a good deal on the subject of ignition occurred both in the discussion and the correspondence, he took this opportunity of saying emphatically that the hot-tube ignition was not always reliable, and the system was antiquated. Electric ignition was very much superior in every way, and purchasers would do well to insist on having such ignition fitted to all new gas-engines. He had had the original tube ignition of the 650 I.H.P. " Premier " gas-engine replaced by electric ignition with very satisfactory results. The breaking of a 3-ampère current, supplied at 6 volts from accumulators, the circuit including a coil with large self-induction, was found quite sufficient to give a good spark. The ignition block was water cooled, and the sparking contacts were formed by two beads of platinum. The dynamo with permanent magnets and oscillating armature, as described by Mr. John Johnston and used extensively on the continent, was probably the best form of apparatus yet introduced, and in fact left but little to be desired.

On the subject of small Mond plants Mr. Johnston wrote (page 215):—" If Dr. Mond could place on the market a simple small producer to work with cheap bituminous coal, he would simply create a revolution in the use of the gas-engine for all power purposes." Evidently Mr. Johnston had not then heard of the success of the small plant at Sandiacre, concerning which they had had information from Mr. Rollason (page 133) and Professor William Robinson (page 163). The smallest Mond plant yet designed is for 250 H.P.

Mr. Cecil Jones asked about carbon losses (page 217). The common slack used in a Mond producer contained a large percentage of dust, and the figure for the carbon loss included the carbon in the fine dust carried away by the gas from the producer, as well as any small quantity of tar formed. This dust was subsequently all collected, but it was not at present considered worth using again in the producer. Like several other speakers Mr. Cecil Jones passed some remarks upon the question of efficiencies of gas-producers, and

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the reason why the speakers did not agree among themselves, and occasionally regarded the author's figures as misleading, was that the term " efficiency " standing alone was ambiguous. It might be used to mean quite a number of different things including :—

1. The heat obtained by burning the gas generated from unit weight of fuel gasified, divided by the calorific value of the fuel gasified.

2. The sum of the quantities of heat leaving the producer in the exit gases (including chemical, latent, and sensible heat), divided by the sum of the quantities of heat entering the producer both in the fuel and in the blast.

3. The calorific value of the gas, burnt cold, divided by the sum of the quantities of heat in the fuel and in the added steam (i.e. excluding regenerated heat).

4. The quantity of heat which one could get paid for, divided by the quantity of heat for which one had to pay.

5. The calorific value of the gas made, divided by the calorific value of the total fuel used both for gasification and for steam raising.

All these efficiencies were represented by numbers in descending order of magnitude, and each had two values according as the higher or lower heating value of the gas was used. No. 1 was a practical figure, and, in cases where exhaust steam was available or where the steam was raised by gas-engine exhaust gases, was the only figure one need consider. No. 2 might be regarded as the true thermal efficiency of the producer, and might be a useful figure or not according to the kind of producer employed. No. 3 was the thermal efficiency of the plant as a whole, and was higher or lower according as the regenerative system employed was good or bad. It was a real measure of efficiency. No. 4 might be called the commercial-thermal efficiency. It *might* be the same as No. 1, No. 3 or No. 5, according to circumstances. No. 5 was not really a thermal efficiency of a producer, but was a figure which embraced the performance of both producer and boiler. It was, however, the figure usually accepted as the thermal efficiency of any producer working solely with the object of making power- or heating-gas. When the operation of a producer

was modified for the special purpose of recovering by-products from the fuel, the commercial results were probably the only figures that possessed much value. For the Mond producer, when worked for the recovery of ammonia, No. 1 was 84 and No. 5 was 67 per cent., but this last figure included coal for evaporating sulphate liquor as well as for steam raising.

Mr. Cecil Jones reproduced a heat balance sheet (page 218) from a former Paper of the author's. All the heat to be paid for appeared on one side, and the chemical and sensible heat of the gases leaving the producer appeared on the other side; but as the heat of combustion of the gas as given was the calorific value when burnt *cold*, the figure $81 \cdot 02$ did not include the items $5 \cdot 45$ and $8 \cdot 61$ as he stated. Also in the balance sheet, as altered by him, he had made the mistake of assuming that some of the gas generated was used in gas-engines for driving the plant, whereas in reality steam-engines were used and the steam passing through the engines was part of, and was included in, the exhaust steam utilised in the blast. The expression " Heat = work done in engines " was simply the thermal equivalent of the work performed, and *not* the total heat of the steam passed through the engines.

The question put by Mr. J. D. Roots referred to the "Premier" engine (page 222). The water-cooling systems for the motor pistons each included two reciprocating double-tube links with circular stuffing boxes at the joints. One end was pivoted in the bed of the engine, and the other end was fixed to the piston and shared its motion. The cold water entered the links at the pivoted end, passed into the bottom of the hollow piston, overflowed at the top of the internal cooling chamber, and finally returned through the other half of the links. The diameter of the valves of the " Premier " engine, as also their arrangement, could be seen from the illustration, Plate 3. Questions of coal costs were dealt with elsewhere.

With regard to Mr. Rowan's remarks (page 226) and his reference to the Duff producer-plant, he understood that Mr. Duff had no gas-engines working with the producer-gas made at Fleetwood, and Mr. Rowan admitted that the engines to which he

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referred were working with coke-oven gas—a system used many
years ago at Winnington and other places. Indeed, speaking quite
generally there was no successful producer-plant generating power-
gas from bituminous slack and supplying gas-engines in regular
work, other than the Mond plant. Mr. Rowan apparently believed
that it was more difficult to obtain good efficiencies with large gas-
engines than small ones, but the opposite view was correct, and the
largest engine in the country at present held the record for efficiency.
No improvement in steam-boiler design could very materially alter
the position of steam-engine economy. In the first place there was
not much margin, with modern steam boilers and economisers, to
improve upon, and secondly it could not alter the comparatively
poor theoretical efficiency of the steam-engine. Mr. Rowan said
(page 228), " some corrections were needed " in the results of
experiments with a small gas-engine carried out by the author in
1894, and recorded in another Paper. The error assumed was
however not his but Mr. Rowan's, who had overlooked the necessity
of correcting gas volumes for expansion by heat, and by saturation
with water vapour, and these particular experiments were made on a
hot July day.

Professor R. Threlfalls' remarks (page 237), on the effect of
change of viscosity of the gases due to temperature changes during
the inspiration stroke of a gas-engine, were both interesting and
new, in this particular connection. There were many problems of
considerable importance still to be solved in accounting for all that
took place in a gas-engine cylinder. As a minor example, the
difference in the shapes of the curves for " A " and " B " cylinders
respectively, of the Crossley gas-engine (pages 49 and 63), were not
readily understood, and he had contented himself with simply giving
the results exactly as he had found them.

Mr. B. H. Thwaite formulated (page 239) what he considered
to be the ideal qualities for a fuel gas to be used in large
gas-engines where steady running was essential, and gave calorific
values per unit weight of the various constituents found in
producer-gas. As all gas was dealt with by volume, the heat
values were better expressed per unit volume. It was then

seen CO and H were almost equal in value. Mr. Thwaite would have liked the author's experimental data to include "analyses of the gas taken at intervals of fifteen minutes during a run of twelve hours, along with indicator diagrams taken at the time the gas samples were being collected " (page 240).   But with all conditions of load, &c., so uniform as those which actually obtained, it was questionable if the continuous aspirator sample was not more satisfactory and reliable.   The extreme uniformity in the quality of Mond gas as shown, not by samples covering twelve hours only, but by hundreds of tests covering months, or even years, and regularly recorded day and night at Winnington, need not be again dwelt upon ; but surely this, together with the splendid results achieved in actual daily work, was sufficient ground upon which to ask Mr. Thwaite to change his opinion as to the value of Mond gas for use in gas-engines.

In conclusion, he trusted to be allowed to cordially thank those who had criticised his Paper equally with those who had defended it, or added new and valuable material.   He was afraid that the discussion had been of such unusual length that he had had to confine his reply almost exclusively to his critics ; but if so, it was not for lack of appreciation of the remarks of other speakers, which he was sure would receive full weight and consideration.

LECTURE ON
THE STRUCTURE OF METALS.

By Professor J. A. EWING, LL.D., F.R.S., *Member*, of Cambridge,
AT A MEETING OF THE GRADUATES ON
14 January 1901.

Sir Frederick Bramwell, Bart., D.C.L., LL.D., F.R.S., *Past-President*,
in the Chair.

The Lecture was illustrated by lantern views of micro-photographs of various metals. The lecturer began by giving a short general account of the manner in which microscopic examinations were made. It was thirty-six years ago that engineers had this wonderful aid to their profession made available to them, and for this they had to thank, not one of their own number, but a naturalist—Dr. Sorby, of Sheffield. For about twenty-two years the work was much neglected; for the last ten or fifteen years a great deal had been done, and much valuable light had been thrown on the properties of metals by microscopic research. In this connection he might simply mention the names, as English workers, of Professor J. O. Arnold, of Sheffield; Mr. Thomas Andrews, also of Sheffield; and Mr. J. E. Stead, of Middlesbrough. He would refer also to the important researches of Sir W. Roberts-Austen in his investigations on the properties of metals in connection with the Alloys Research Committee of this Institution.

The features he was about to bring forward were for the most part the result of investigations made by the lecturer and his colleague Mr. Walter Rosenhain at the engineering laboratory at Cambridge. In order to gain information upon the structure of a metal by aid of the microscope, it was in general necessary to cut a section, which should have a very fine polish. The height of polish was more especially needful for unaccustomed observers, in order to remove appearances not germane to the phenomena under consideration. As the student grew accustomed to such observations, he learnt to distinguish accidental defects and to make allowance for them. The section having been polished, it was then as a rule lightly etched in order to bring out the structure.

The first slide thrown on the screen was that of a micro-section of wrought iron of the best Swedish quality, selected because of its freedom from slag. There were patches which, however, could easily be distinguished. It would be noticed that the image was divided up by boundary lines into a number of irregular patches, much as a map of England would be into the various counties. Each of these patches was a true crystal; and here he explained that a piece could be a true crystal although its boundaries were not of simple geometrical form. It might be of irregular shape so long as the particles composing it were all disposed in one direction, or, in other words, had the same orientation. There could be little doubt that all metals in any form were crystalline, and the old distinction drawn by engineers, that a certain specimen was or was not crystalline was out of date; although, to a practised observer, the crystalline appearance of the fracture was as good a guide as ever to the physical properties of the substance. In order to discover the orientation of the crystals, the specimens had to be illuminated from different directions. For instance, if the light were thrown on to the specimen parallel to the axis of the tube of the microscope, facets that were normal to that line would reflect light and appear light in the image. If, on the other hand, the illumination was oblique, the surfaces before shown light would appear dark, whilst some of the dark patches would be changed to light ones. These effects were shown very plainly by a number of slides. The pits

due to etching—which always had the same orientation over any individual crystal—and the appearance produced by occluded gases, were also illustrated.

The way in which crystals were formed, during the solidification of a metal whilst cooling from a molten state, was illustrated by micro-photographs of cadmium, a substance particularly favourable for the purpose. The lecturer used the simile of a number of children playing on a nursery floor with unlimited supplies of boxes of bricks. It was necessary to suppose that solidification of the metal would begin at one or more points. It was as if the children started, at a given signal, to build castles on the floor as fast as they could. Each child would put down a brick and then another beside it, and then another, all touching each other and arranged in one direction, and this would go on until the castle of one child touched the boundary of another's, and so on until there was no space left. That would represent the solidification of the metal, and though the bricks individually would be similar, no two neighbouring groups need be pointing in a like direction. There were, however, to be seen in the image on the screen, distinct boundary walls between the crystals; and at these boundaries there tended to accumulate what he would call the sweepings of the nursery floor. As each child built its castle, it pushed before it the dust on the floor until it was imprisoned between the adjoining structures. This at least was true for small quantities of foreign metals, but a piece of slag might keep its place and be enclosed as the crystal grew round it. In impure metal the boundary walls were composed of alloys, which, being more fusible than the metal, were swept out as the crystal formed, and were the last thing to solidify. The alloys, therefore, formed a cement which held together the different crystals.

The next point dealt with was the effect of strain in the crystalline formation. Thin strips of metal were subjected to tension under the microscope, by means of a thumbscrew attached to the stage, and in one instance the microscope was mounted above a test-piece on the testing machine itself. Whilst the specimen was stretched only within the elastic limit, there was no visible action, although the crystals must have changed somewhat, however minutely; but when.

the plastic stage was reached, there was a visible effect. There appeared across the specimen, as shown by a slide, dark lines, more or less normal to the direction of stress. These dark lines had all the appearance of crevasses or cracks, when the illumination was in line with the tube of the microscope. On directing the light obliquely, however, the dark lines became bright lines on a dark ground. The explanation of this phenomenon was that the specimen had not fissured, otherwise no light would have been reflected from the cracks in any case, but the specimen had elongated by the slipping of the components of the crystals past each other. It was as if one were to take a pack of thick cards and squeeze it sideways, so that the cards would slide a little way on each other. The edges would then overlap, forming, as it were, steps, or what an architect would describe as "risers." It would be easily understood that light would be reflected either from the edge of the card or from the small area of surface exposed, according to the angle of incidence. From these facts it was to be argued that plastic yielding meant slipping of the parts of each crystal upon other parts of the same crystal. Generally the slipping took place in more than one plane, and an example was shown of four well-defined systems of parallel slip lines.

However violently a metal might be strained, it still preserved the same crystalline structure. This followed from the fact that plastic strain occurred by means of slips on the cleavage or gliding planes of each crystal. Sections of cold rolled metal were exhibited illustrating this. The phenomenon known as "twinning" was also illustrated and briefly described. The lecturer stated that iron apparently never twinned, though copper and most other metals often did so when subjected to severe strain. The effect of "twinning" was to produce two lines of slip forming a definite angle with each other.

The effect of temperature was next dealt with, and it was shown how heat, even moderate heat, would change the crystalline structure of metal that had been strained. Professor Ewing had secured a specimen of rolled lead which had been supplied for roofing the Cambridge Laboratory. A micro-photograph prepared from

this showed very large crystals, which were somewhat surprising considering the way the metal must have been strained during the process of rolling. It was concluded, therefore, that some sort of annealing process had taken place, and this was confirmed by a series of experiments in which the changes which gradually took place in strained lead were watched. An endeavour was made to observe what occurred whilst a metal was actually cooling from a very high temperature. A specimen of iron was brought to a white heat, and brought within the field of the microscope of high power, the lens being protected by a blast of cold air interposed between the microscope objective and a vacuum tube containing the iron, which was heated by an electric current. As a *tour de force* the experiment was successful, but the results were barren. The changes in the crystalline structure could not be followed, the structure seen being only the result of the etching. In order to observe the results of any re-crystallization, it would be necessary to repolish and re-etch the specimen. It was determined therefore to be content with observing results after they had been obtained, and not to strive to watch them in progress.

Returning to the experiments with lead, some specimens were subjected to very great pressure, so that the crystals were broken up, and they were then put by for a time in a room at atmospheric temperature of about 50°. After two months the effect of annealing at this low temperature was to increase the size of the crystals, and after five months the effect was still more marked, as was shown by the lantern slides. Other slides were exhibited showing how greatly the effect was hastened by heat, a temperature of 200° C. producing a very marked effect in five minutes.

An interesting and curious phenomenon described by the lecturer was the way in which " competing crystals " would struggle for existence and eat up one another during the process of annealing. A series of slides of a specimen of lead illustrated this; one aggressive crystal gradually invaded another, until the first was in a fair way of being absorbed. The same thing was illustrated in the case of cadmium. The explanation of the invasion of each other's territory by crystals was interesting. The theory was suggested by

Mr. Rosenhain, and Professor Ewing expressed his agreement with it. It was concluded that the envelope of alloy which surrounded a crystal, and made the boundary wall which separated it from the one adjacent, would be broken by the strain to which the metal had been subjected in cold rolling. A difference in potential between the metal and the alloy would set up electrolytic action, and this would cause a solution of one crystal into the alloy between and a deposit upon the adjoining crystal. The fact was illustrated by slides showing the action of two pieces of lead. These were welded by being scraped perfectly clean and then pressed together with great force. A micro-section including the weld showed a straight line of demarcation, the crystals of either piece not intruding over the boundary into the other part of the specimen. When, however, a little powdered tin was sprinkled on the scraped surfaces before squeezing them together, the crystals grew across the plane of the weld, those of the formerly two separate pieces intruding amongst each other, the tin introduced forming a boundary layer, in which electrolytic action could take place.

A large number of photographs were exhibited by the lecturer, a few of which are reproduced on Plates 12–17.

Fig. 1, Plate 12, illustrated the effect of etching in developing pits, which were similarly oriented over any one crystal. In this case the greater part of the area shown was taken up by one crystal, on which etching had developed many rectangular pits, the sides of which were parallel from pit to pit.

Fig. 2 illustrated the effect of etching on the comparatively large crystals of tin found in commercial tin-plate. The area shown included parts of two crystals, and the geometrical structure of each was well brought out.

Fig. 3, Plate 13, showed boundaries and " air-pits " in cadmium, as cast on a surface of smooth glass. The air-pits were seen to be similarly oriented over each individual crystal. In solidifying, the metal built itself round these pits, which were due to tiny bubbles of air or gas given out during solidification. The boundaries were marked by an accumulation of such air or gas.

Fig. 4 showed air-pits in another piece of cadmium, under a higher power (4,200 diameters in the original photograph).

Fig. 5, Plate 14, showed slip lines as developed by severe straining in soft iron.

Fig. 6 exhibited twin systems of slip lines due to twin crystallization in copper.

Fig. 7, Plate 15, showed slip lines developed by straining on lead.

Fig. 8 was the same piece of strained lead as Fig. 7, but illuminated by oblique light, the effect being that certain systems of slip lines appeared bright on a dark ground, while other systems were invisible.

Figs. 9–11, Plates 16 and 17, showed the gradual annealing of lead by continued exposure to a temperature of 200° C. Fig. 9, Plate 16, showed a marked area when the metal was freshly strained by severe crushing, and before the process of annealing began. Fig. 10 was the same area after seventeen hours' exposure to 200° C. Fig. 11, Plate 17, showed, on a rather small scale, the same marked area and the adjoining portions of the surface as they appeared after the process of annealing at 200° C. had been going on for forty days. The most interesting feature then apparent was the growth of one very large and aggressive crystal, which extended over a large part of the area photographed.

The photographs, which had been taken by Mr. Rosenhain, were selected from a more extensive series already published in the Philosophical Transactions of the Royal Society, in illustration of two Papers by Professor Ewing and Mr. Rosenhain, on the Crystalline Structure of Metals,* which may be referred to for a fuller account of the subject treated of in the lecture.

Mr. H. M. ROOTHAM, Graduate, proposed, and Mr. W. H. TREGONING seconded, a hearty vote of thanks to Professor Ewing for his interesting and valuable lecture.

* Philosophical Transactions of Royal Society, vols. 193 and 194.

The CHAIRMAN, in putting to the Meeting the vote, which was carried unanimously and with applause, instanced a practical illustration of the phenomena described by Professor Ewing in the breaking of helve hammers. These had to be kept a year or so after they were cast before they were put into use, otherwise they were nearly sure to fracture. The strains set up in cooling after casting put the metal into the state of tension referred to by Professor Ewing, and time was needed to dissipate this tension.

Professor EWING thanked the Meeting for the very kind reception which had been accorded to him.

The Meeting terminated at Half-past Nine o'clock. The attendance was 106 Graduates and Visitors.

POWER-GAS AND LARGE GAS-ENGINES.

Plate 1.

Fig. 7.

Fig. 5.

Fig. 6.

Fig. 8. *Details of Flywheel.*

Steel key in three pieces, carefully fitted and driven on, having ⅛ in. taper to 1 foot.

Teeth

Fig. 9.

400-H.P. Gas-Engine (Crossley).

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Plate 2.

Plate 2.

POWER-GAS AND LARGE GAS-ENGINES.

500-H.P. Gas-Engine
(Premier).

Fig. 10.

Fig. 11.

Fig. 12.

Fig. 13.

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Plate 3.

POWER-GAS AND LARGE GAS-ENGINES.

Fig. 14.
Section of
Admission- and
Gas-Valves.
Scale 1/8th.

500 H.P. Gas-Engine (Premier).
Positive Scavenger Type.

Fig. 15.
Scale 1/8th.

Gas
Inlet

Air Ports

Air Ports

Admission Valve

Exhaust Valve

Admission Valve

Exhaust Valve

Plate 3.

Fig. 17. *General View of Mond Gas Plant, Winnington, Cheshire.*

Fig. 18. *The Producers.*

Fig. 19. *Mond Gas Plant, Regenerator.*

Fig. 20. *Washer, etc.*

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Plate 6.

POWER-GAS AND LARGE GAS-ENGINES. *Plate 6.*

Fig. 25.

1500-H.P. Gas-Engine (Westinghouse).
Proposed Electric Station containing 20 Engines.

Tuning-Fork Cyclometer (see Appendix V., Table 4).

Fig. 33.

Fig. 34.

Plate 8.

Plate 8.

POWER-GAS AND LARGE GAS-ENGINES.

Fig. 37. 600-N.H.P. Gas Blowing-Engine (Cockerill).
Fed with blast-furnace gas.

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Plate 9. POWER-GAS AND LARGE GAS-ENGINES. *Plate 9.*

Fig. 39.

*600-H.P. Two-cycle
Gas-Engine (Oechelhaeuser).*

Fig. 40.

*1000-B.H.P. Gas-Engine,
using blast-furnace gas.
(Gas Motoren Fabrik, Deutz.)*

A. *Air.* E. *Exhaust.*
G. *Gas.* M. *Gas and Air.*

(The Swiss Locomotive and Engine Co.'s Communication.)

Fig. 51. 100-H.P. Gas-Engine (Winterthur), using Dowson Gas at Embrach.

Indicator Diagrams.

Stroke = 31½ inches

Diameter of Cyl. = 20½ inches

Water Jacket

Exhaust Valve

Admission Valves

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(The Swiss Locomotive and Engine Co.'s Communication.)

Fig. 52.   200-B.H.P. Gas-Engine (*Winterthur*).
(*Detail for Oiling Crank-pins, see Fig. 54.*)

(Herr Max Munzel's Communication.)

Fig. 53.   1200-B.H.P. Gas-Engine (*Deutz*) using blast-furnace gas at *Hoerde.*
(*Indicator Diagram, see Fig. 46.*)

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Fig. 1. *Iron × 800 diams.*

Fig. 2. *Tin (Tin-plate) × 100 diams.*

Plate 13.

Fig. 3.

Cadmium
× 1,000 diams.

Fig. 4.

Cadmium
× 1,200 diams.

Mechanical
Engineers
1901.

Fig. 5. *Soft Iron (severely strained)* × 400 *diams.*

Fig. 6. *Copper* × 1,000 *diams.*

Fig. 7.   *Lead (strained)* × *100 diams.*

Fig. 8.   *The same, illuminated by oblique light.*

Fig. 9.
Lead (crushed).

× *12 diameters.*

Fig. 10.
*The same after
17 hours annealing.*

*Mechanical
Engineers
1901.*

Fig. 11.   *Lead (strained by crushing).*

Same surface as Figs. 9 and 10, Plate 16, after 40 days annealing.
× 8 diameters.

Illuminated Address
from the American Society of Mechanical Engineers.

Mechanical Engineers 1901.

To the King's Most Excellent Majesty.

May it please Your Majesty.

The President, Council and Members of The Institution of Mechanical Engineers at this their first Meeting held since the death of Her Gracious Majesty Queen Victoria, desire to express their high appreciation of Her most noble life and their profound sympathy with Your Majesty and the Members of the Royal Family.

The Council and Members also desire to offer their dutiful and most hearty congratulations on Your Majesty's Accession to the Throne.

Your Majesty's interest in Engineering Achievements has been shown in many ways and has been evidenced by Your gracious acceptance some years since of the Honorary Membership of this Institution. The progress of Mechanical Invention has been a marked feature during the long reign of our late revered Queen, and they trust that Engineering Science will continue to progress under Your Majesty's fostering care.

They pray that the blessings of health, long life, prosperity and happiness may be vouchsafed to Your Majesty and to Your august and beloved Consort, Queen Alexandra.

W. m. maw   President

Mechanical Engineers 1901.

W.N. maw.

The Institution of Mechanical Engineers.

PROCEEDINGS.

15th February 1901.

The February General Meeting was held at the Institution on Friday, 15th February 1901, at Eight o'clock p.m.; William H. Maw, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

TRANSFERENCES.

The President announced that the following four Transferences had been made by the Council :—

Associate Members to Members.

Bulwer, Ernest Henry Earle, . . . Grimsby.
Hyde, George Herbert, ... Colombo.
Porritt, Louis Alfred, ... Rochdale.
Taylor, William, ... Leicester.

The following Paper was then read and discussed :—
" Light Lathes and Screw Machines "; by Mr. John Ashford, *Associate Member*, of London.

The President announced that, as the Discussion had not been concluded, an Extra Meeting would be held on Friday, 22nd February.

The Meeting terminated shortly before Ten o'clock. The attendance was 123 Members and 120 Visitors.

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PROCEEDINGS.

22nd February 1901.

An Extra Meeting was held at the Institution on Friday, 22nd February 1901, at Eight o'clock p.m.; William H. Maw, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The Discussion was resumed and concluded on Mr. Ashford's Paper on " Light Lathes and Screw Machines."

The Meeting terminated at Ten o'clock. The attendance was 68 Members and 50 Visitors.

LIGHT LATHES AND SCREW MACHINES.

By Mr. JOHN ASHFORD, *Associate Member*, of London.

Many changes have taken place during the last few years in the methods of machining in our various engineering establishments and manufactories, changes which are necessary in the march of progress, and which we must and do recognise as essential, in order that, as a country, we may maintain our position in the manufacturing world. These changes in machining methods usually accompany modifications in the schemes of works management, the object being to systematise the output of work, so that prime costs may be reduced to the lowest point, while the quality of the productions, as regards both accuracy of size and fineness of finish, may be all that can be desired. In order that these new schemes of organization may be satisfactorily carried out and all requirements of the new order of things fulfilled, there has been a demand for machine tools which in themselves shall fit into the scheme, be more handy for their work, be capable of producing numbers of an article exactly alike, be automatic where possible in their action, and shall require little skilled attention. That the changes in themselves are great may be realised, when we consider to what an extent milling processes have supplanted shaping and slotting, and more especially hand-finishing; how grinding is now used for finishing work that has previously been turned; and

how at present automatic machines are being introduced for producing
in quantities machine parts which had hitherto to be made by skilled
men at a much higher cost.

In what manner these methods originated it is difficult to say ;
but in all probability they were first introduced in the manufacture
of watches and clocks in large numbers ; then in the production of
small-arms, sewing machines, type-writers and the like ; and later
in the construction of cycles. Engineers have now without doubt
recognised the fact that similar methods may be employed in the
manufacture of larger machines, locomotives, and even bridges and
ships.   These changes have not been suddenly brought about,
although to some it might appear so ; but they are in fact the result
of steady progress.   To those who have not kept abreast of the
progressive movements, the changes may have been forced upon their
notice with unpleasant suddenness by the experience of foreign
competition.   Probably there may be establishments with which some
of our members may be connected, where it is realised that alterations
in the producing machinery must be made, yet there is hesitation in
incurring the heavy outlay necessary, before they have thoroughly
considered the matter and are satisfied as to the results likely to
accrue.

That the matter is serious is evident from the fact, that in certain
manufactories whole shops have been cleared of their machines and
a completely new and up-to-date plant installed. This Paper has
therefore been prepared, in order to create an opportunity for the
discussion of the details of machine tools upon which much
thought has been bestowed.   By the term "*light lathes*," here
employed, it is intended to indicate lathes, such as engineers use,
in which the centres are below 10 inches.   The ordinary lathe,
with which we were satisfied ten years ago, does not fulfil the
requirements of the present day.   There is no disputing the fact that
it was a good serviceable tool, but the necessities of these times
demand a machine which may be more smartly worked, be more
handy, and cause less loss of time. What then are the requirements
of a modern lathe for tool and ordinary work, and how may these
be fulfilled ? In answer to the first part of this question, the author

puts forward his views with all deference, in the hope that members will also state theirs ; and, in answer to the second portion, by way of solution, he ventures to point to certain existing designs.

Let it be granted as a first principle that the machine should be stiffly constructed, and so lined up and fitted that initially it may do satisfactory work ; then :—

(a) Its wearing parts should be made of such material, and so shaped, proportioned, and protected, that its wear may be reduced to a minimum, and its accuracy be maintained, and that such wear as takes place may be compensated by adjustments.

(b) The various changes of speed, of traverse, of tool position, of tail-stock position, &c., should be effected by handle movements, which should be practically instantaneous in action and within easy reach of the operator. The use of a spanner for any of these purposes is undesirable.

(c) A reasonable change of speed should be possible without handling the belts.

(d) All ordinary speeds of traverse should be obtained without the removal and changing of spur-wheels or belts.

(e) When screw-cutting or chasing from the leader screw, a single movement should suffice to release the screw and withdraw the tool from the work.

(f) When taper turning, it should not be necessary to disturb the alignment of the tail-stock, or the set of the rest.

(g) Feed stops should be introduced, and also means of reversing the feed traverse.

(h) It should not be possible for any two speeds of traverse to be in action at one time.

It is difficult to specify exactly the requirements of a *turret lathe*, as so much depends upon the nature of the work to be machined. It may however be conceded that many of the requirements set forth in paragraphs (a) to (h) apply with equal force to turret lathes, and in addition the following :—

(i) When working from the bar, a self-centering chuck must be fitted, which shall have sufficient power and range of action to grip the bar securely when subjected to its heaviest cut, and shall allow for ordinary variations in the diameter of rough stock whilst taking its grip, without moving the stock longitudinally.

(j) There should be a suitable means of feeding forward the stock when required, without undue loss of time, and the feed should come into action immediately the chuck is released.

(k) The design of the revolving tool-holder or turret should be such as will allow the greatest range of action; hold a sufficient number of tools for all ordinary work; support the tool without spring under the heaviest cuts; bring the tools into action, accurately adjusted; simplify the construction and setting of tools and their holders; and revolve and adjust itself automatically.

(l) Independent stops should be provided for each tool, and, when the turret traverse is actuated by power, the stops should throw out the power mechanism.

(m) The means of traversing the turret should be such as to allow of quick movements while changing the tool positions, and of steady motions while cutting.

(n) A cross slide is usually desirable to carry forming, cutting-off, and chasing tools, and its position should be easily and accurately adjustable.

(o) In many cases, especially for brass work, efficient means of chasing should be introduced; and if for this purpose a leader screw is used, excessive wear of the screw should be guarded against.

Full automatic screw-machines, suitable for automatic turning in addition to screw-making, may be considered to be modified turret-lathes, with mechanism added to regulate the various movements automatically. The requirements of the turret lathe thus apply also largely to this class of machine, and in addition the following :—

(p) The headstock should retain some of the features of the turret lathe, with modifications adapting it to automatic working. The speed of spindle rotation should be variable to a limited extent; but the introduction of self-opening dies has rendered it unnecessary to provide any reversing mechanism.

(q) A cam-shaft must be introduced to regulate the movements of the various parts; and, as the speeds of the movements are required to vary, the cam-shaft speed should be changeable, the variation being quite independent of the spindle speed.

(r) It is a debateable question as to whether the turret carrying the tools should have a constant or a variable distance of forward traverse. The settlement of this point greatly affects the design of the machine, and in the author's opinion the correct answer is that, unless the scope of the machine is to be restricted, the forward traverse should be variable.

(s) The mechanism controlling the tool movements should provide for a rapid withdrawal of the tool and change of position, so that idle time may be reduced to a minimum.

The question now is:—How may the requirements of the foregoing paragraphs be best fulfilled; and to what extent do they affect the construction of the machines?

Respecting paragraph (a), the wearing parts which affect the accuracy of the machine are the journals and bearings of the spindle; the various slides and slide surfaces; the screws and their nuts. That a wearing surface may act satisfactorily, it is recognised that the following conditions should be fulfilled:—

(1.) That any pressure brought to bear upon it should be evenly distributed.

(2.) That it should be protected from dirt of every description.

(3.) That it should be efficiently lubricated.

(4.) That the surface itself should be sufficiently large.

(5.) And finally that its formation should not admit of any pressure brought to bear upon it being mechanically increased to any serious extent.

(See Plates 20 *and* 21.)

The Spindle.—It is **a** point for debate as to whether the spindle should be hard or soft. In the opinion of the author, it is of much more importance that the bearing surface should be large, and the journals be made truly cylindrical.

The Bearings.—As materials, each of the following is found to have been used :—hard steel, cast-iron, phosphor-bronze, and brass or cast-iron lined with white metal. When the bearings are small, no doubt hard steel is desirable ; but if they are of ample proportions, it becomes unnecessary. Too soft a metal, on the other hand, is not satisfactory, as it does not last well enough. Both phosphor-bronze and cast-iron may be considered suitable : that is, if the bearings are well bedded, and of sufficient diameter and length to satisfy condition (4) respecting wearing surfaces.

Several different forms of spindle bearings are shown in Figs. 1 to 5. The conical construction, as in Figs. 1 and 2, has the rather serious objection of failing to comply with condition (5) in regard to wearing surfaces ; for, should the thrust-bearing be improperly adjusted, the cone will be forced more deeply into its bearing, thus increasing the pressure on the surface, and thereby creating excessive friction. The cone-bearing in fact does not lend itself to either of the conditions (4) or (5), because with a reasonable taper the bearing is short ; but if, on the other hand, the length is increased, there is a finer taper, which still further violates condition (5).

The author prefers the design shown in Fig. 3, where the bearing surfaces are parallel and the exterior of the bearings is coned. The bearing is split in one place and eased in two others, thus making a springy bush, which, when adjusted longitudinally, will close upon the journal. This retains the advantage of the cone adjustment with a parallel bearing. In this same bearing, conditions (2) and (3) are well satisfied, as there is a felt oiling-pad introduced into the split of the bush, and dust-caps over the ends of the bearings. Halved bearings are largely used ; and ball-bearings, as in Figs. 4 and 5, have been tried.

Spindle Bearings.

Fig. 1

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Thrusts.—With the cone-bearing, an adjustable end-thrust, such as in Figs. 6 and 7, is necessary; but, when parallel bearings are used, a non-adjustable ball-thrust is satisfactory, and it may be placed inside the poppets, thus adding to the compactness of the headstock. Ball end-thrusts may be seen in Fig. 3; Fig. 28, Plate 22; and Fig. 53 (page 282).

Thrust Bearings.

Fig. 6.   Fig. 7.

Adjusting or Gib Strips.—Several different arrangements of these strips are illustrated in Figs. 8, 9, 10 and 11. Those in Figs. 10 and 11 should undoubtedly be used where possible, and the strip should have sufficient metal in it that only two adjusting screws may be necessary. It cannot be considered good practice to use thin strips with three or more grub-screws for adjustment.

Adjusting or Gib Strips.

Fig. 8.   Fig. 9.   Fig. 10.   Fig. 11.

Slide Surfaces.—That slide surfaces may wear well, the conditions as to wearing surfaces should be met as fully as possible. When the force applied for the purpose of traversing a slide is not central with the resistance, a couple results with a tendency to twist the slide. A very small angle of twist causes condition (1) to be violated; consequently, unless the strips are so adjusted that there is no slack, the condition cannot be satisfactorily complied with. This leads to the

following conclusions :—either (1), the screw or other means of traversing the slide must be in line with the resistance ; or (2), where that is impossible, as it usually is, and as an ordinary machine operator cannot be depended upon to keep the strips correctly adjusted, the adjustments must be automatic ; or (3), the guide surfaces in contact should be very long.   From these points of view,

Lathe-bed Sections.
Figs. 12–20.

English

12

American.
(Lodge and Shipley)

13

American
(Jones and Lamson)

14

English
(Humpage Jacques
and Pedersen)

15

American

16

Small Capstan

17

With   Inside   Screws.

18

German.(Pittler)

19

Small German

20

it is evident that the nearer a traverse-screw is to the centre of the slide-ways, the better.   The usual practice with the slide-rest conforms to this ; but not so with the saddle, although some firms put the leader-screw in the interior of the lathe-bed.

Now as regards the shape of the slide-ways of the bed, how do the above conclusions affect their form ?   As it is impossible to apply

the traversing force to the saddle in line with the resistance, and
as it is not desirable to make the guide surfaces so long as would be
required by the third conclusion, the second should be considered
more closely.   That the saddle may have no tendency to twist under
the action of the traversing force, this conclusion requires that the
guide surfaces shall automatically adjust themselves to each other.
On inspecting then the various bed-sections illustrated in Figs. 12
to 20 (page 267), to see if either is of a form that will provide this
automatic adjustment, it will be found that those having raised Vs
undoubtedly do so, for gravity acts as a closing force, keeping the
surfaces in contact.

Considering the remaining conditions (2), (3), (4), and (5), as
affecting bed-sections, condition (2) requires protection from dirt.
A shape which affords the least facility for catching dirt, or more
especially metal particles which would work in between the rubbing
surfaces and cause rapid wear, is one having a sloping surface, such as
those in Figs. 13, 14 and 16.   The possibility of satisfying condition
(3) follows on a fulfilment of condition (4), provided that there are
ample means for the continuous application of oil, which is rarely
the case.

English lathe-builders pride themselves upon the ample surface
supporting the saddle, as obtained by the shape in Fig. 12, which is
lost by the use of raised Vs.   No doubt such a form has the
decided advantage of giving direct support to the saddle, and reducing
spring to a minimum.   The great disadvantage of the raised V form,
as in Figs. 13 and 16, is the lack of support for the saddle
immediately under the tool-rest.   The saddle fits upon the two
outer Vs, and thus has a long span, so tending to make it weak in
the back and lacking in stiffness.   If however the inner Vs are
placed at a lower level, it allows of an increased thickness in the
saddle, which tends to minimise this disadvantage.   Moreover if the
cross slide-way is raised upon the saddle, instead of sunk into it, the
slide which fits upon it may be of greater length, thus giving a
better distribution of the pressure from the tool when cutting, and
thereby adding to the stiffness.   Such an arrangement has the further
advantage of protecting the cross slide-way from metal cuttings.
Ample support for the saddle is desirable ; but broad flat slide-surfaces

on the bed are not unmixed blessings, for they easily catch the metal cuttings, which then work under the saddle and form the chief factor in the wear of those parts. All things being considered, the author is of opinion that the requirements of paragraph (a) are more nearly met by a bed-plate with raised **V**s, the inner pair being set lower than has hitherto been the practice.

Release-nut Clutch.—The accuracy of the machine for screw-cutting will be affected by the construction of the clutch which works the release-nut. There should be no possibility of side-flexure. Figs. 21, 22, and 23 show three ways of constructing this clutch.

Release-nut Clutches.

Fig. 21.	Fig. 22.	Fig. 23. Inside Screw Clutch (Hetherington).

Traverse Screw

0   5   *Inches* 10

With regard to paragraph (b).—It is one of the essentials in modern factories that a cutting tool shall be made to work at as high a speed and with as heavy a cut as can be employed in combination; which usually means frequent changes of speed to suit different diameters and variations in depth of cut. The average workman is not, as a rule, particularly keen to get the utmost from his machine, and, the greater the trouble to change the speed, the less often will he do it. It therefore follows that the more easily and quickly a change can be effected, the more likely is the machine to approach its maximum output. This points to the wisdom of making a machine handy, to meet the requirements of paragraph (b). How then may these quick

variations of speed be obtained ?   Firstly, in the drive from the main to the counter-shaft, by using several sets of pulleys of different diameters, or by friction-cone drives, or expanding pulleys ; secondly, by ordinary stepped-cones in the drive to the lathe ; and thirdly, by frictional back-gearing.

Friction-cone drives have been more put forward of late. Messrs. Ward are making a facing lathe which has a chain connection from the cross-traverse screw to the striking fork, so that as the screw is rotated to traverse the slide-rest, a motion is transmitted to the striking fork by the chain.   The relative motions are so arranged that, when the cutting tool is advanced towards the lathe centre, the striking fork is moved to give a greater speed to the lathe spindle, thus maintaining a constant cutting speed.

Back-gearing, as originally fitted, was rather troublesome to put into and out of gear, necessitating the stoppage of the machine and the use of the spanner.   The introduction of friction back-gearing is an improvement that greatly facilitates the change of speed, and is undoubtedly a valuable feature in the modern machine, which might with advantage be more generally introduced.   A headstock with friction back-gear is illustrated in Plate 22.   With a headstock of this description, practically an instantaneous change over of the back-gearing may be made; and for this purpose friction-clutches are introduced into the interior of the belt-cone and the large gear on the spindle.   These friction-clutches are made with an expanding brake-strap, and the expansion movement is produced by a simple form of toggle-joint A, Plate 22.

Changes of Traverse.—A further requirement of paragraph (b), namely that the changes of traverse should be effected by a handle movement practically instantaneous in action, is most important, both for ordinary turning and for screw-cutting.

An examination of the following methods now in use will be of interest.   The change feed-motion largely adopted for the purpose of driving the traverse shaft and leader screw, is shown in Fig. 29, Plate 23 ; it is part of an open-spindle capstan-lathe.

* A short driving-spindle A is mounted parallel to the traverse shaft B, and three pairs of wheels, CF, DG, and EH, mesh together upon the shaft and spindle. The wheels upon the spindle have each six keyways; and they are also counterbored, as shown at I. The spindle is bored and slotted to receive a rod J, armed with a cross-piece, which acts as a sliding key K. The handle, situated in front of the gantry, is used to slide the rod with the key K, its position determining which of the pairs of wheels shall be operative. The centres of the shaft and spindle are $3\frac{2}{3}$ inches apart, and the wheels are paired as follows :—

First pair.	C $3\frac{1}{4}$	inches pitch diameter,			39	teeth.
	F $4\frac{1}{16}$	,,	,.	,,	49	,,
Second pair.	D 4	,,	,,	,,	48	,,
	G $3\frac{5}{16}$	,,	,,	,,	40	,,
Third pair.	E $4\frac{1}{2}$	,,	,,	,,	54	,,
	H $2\frac{13}{16}$	,,	,,	,,	34	,,

The pitch is 12 diametrical, and the feeds are $\frac{1}{3\frac{1}{2}}$nd, $\frac{1}{2\frac{1}{4}}$th, and $\frac{1}{16}$th respectively.

Messrs. John Hetherington and Sons use a similar mechanism with four changes of speed to drive their sliding and surfacing shaft in their 10-inch sliding, surfacing and screw-cutting lathe.

In the arrangement for a similar purpose, Fig. 30, Plate 23, there is also a driving spindle and traverse shaft. There are three pairs of wheels, but they are not continually in gear.

Those marked 1, 2 and 3 are each pinned to the traverse shaft. Upon the driving spindle there is a sleeve which is free to slide upon a feather key. Mounted upon it and forming part of the sleeve are three wheels, 4, 5, and 6. The position of the sleeve can be regulated by a handle in front, which may cause either pair of the wheels to mesh as follows :—

First pair.	No. 1 has 55 teeth 10 pitch.				
	No. 4	,,	35	,,	10	,,
Second pair.	No. 2	,,	35	,,	10	,,
	No. 5	,,	55	,,	10	,,

* Descriptions of the construction and method of working of the various Machines mentioned in the Paper are indented.

Third pair.   No. 3 ,, 45 ,, 10 ,,
                     No. 6 ,, 45 ,, 10 ,,

The feed-change gear in Plates 21 and 24 is a modification of that shown in Fig. 29. The drive in this case is by roller chains, with three pairs of sprocket wheels. The driven wheels are mounted upon a sleeve which rides upon the end of the traverse screw, and sliding keys are provided within the driven wheels.

The change-wheel feed-gear shown in Fig. 31, Plate 23, which is usually known by the name of the Hendey-Norton gear (lathe, Fig. 25), is a handy arrangement, and has been much copied. It serves to regulate the traverse for both screw-cutting, turning and facing. That it may apply for these several purposes, the leader screw is cut with a keyway along its length so that it serves both as a screw and a traverse-shaft. It will be interesting to learn the opinions of members on the use of the leader screw in this dual capacity. Change-wheels are employed in the usual manner, the intermediate wheels being mounted upon a quadrant; but the number is limited, as there are only two with 36 teeth, one with 140, and one with 69 teeth; the last however is used but rarely.

In front of the gantry is a gear-box, through which the leader screw passes, and upon the portion within the box there are twelve spur-wheels, the teeth ranging in order as in Table 1. Directly beneath the screw is a short shaft, upon which, and within the gear box, is mounted a sliding tumbler containing a pair of spur-wheels, the first upon the shaft and the second in gear with the first. This tumbler may be moved along the shaft until it is opposite any one of the wheels upon the screw; it is then raised to cause the second wheel to mesh with that upon the screw, where it is held in position by a spring catch. This action closes the train of wheels when the change-wheels have been set. In order that one of the change-wheels may be mounted upon it, the end of the short shaft projects beyond the gear-box; and thus the motion from the mandrel is transmitted by the change-wheels and the short shaft, and thence through the medium of the gears in the tumbler to the leader screw.

In Table 1 the screw-threads which may be cut are placed in order below the figure indicating the number of teeth in the wheels, and the change-wheels are arranged as indicated on the left. An inspection of the figures will show that all ordinary requirements are met when the two change-wheels with the 36 teeth are in use. Consequently it is but rarely that, beyond the movements of the tumbler, a change of the wheels is necessary. When the reducing gear inside the apron is in action, the numbers of threads cut per inch are increased seven times. The gears in the tumbler have 30 and 63 teeth.

TABLE 1.

Change-Wheels and Screw-Threads. (*Hendey-Norton.*)

Number of Teeth on Change-wheels.		Number of Teeth on Spur-wheels in gear-box.											
on stud	on shaft	30	35	40	45	50	55	60	65	70	80	90	100
Teeth.	Teeth.	Number of Threads cut per inch.											
144	36	5	$4\frac{1}{2}$	4	$3\frac{1}{2}$	$3\frac{1}{4}$	3	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$	2	$1\frac{3}{4}$	$1\frac{1}{2}$
36	36	20	18	16	14	13	12	11	10	$9\frac{1}{4}$	8	7	6
36	144	80	72	64	56	52	48	44	40	36	32	28	24

In the No. 6 hexagonal turret, Fig. 72, Plate 36, there are two feed-change gears; one is connected with the leader screw, and the other with the traverse-shaft, each of which passes along the front of the lathe. The gear for the leader screw has four changes, which are obtained in a simple way, Fig. 34, Plate 25.

Four spur-wheels 1, 2, 3, 4, are fitted upon and form part of a sleeve, which is free to rotate upon the fixed stud 5. Pivoted upon a second fixed stud 6 is a built-up swing-frame, carrying an intermediate wheel 7, the position of which may be varied upon the sleeve 8. Upon the fixed stud 6, and within the part embraced by the swing-frame, is a broad spur-wheel 9, which when in motion is driven by the intermediate wheel 7. The

wheel 7 may thus move into either of four positions upon its carrying sleeve 8, and still mesh with wheel 9. By lifting the swing-frame, the wheel 7 may be caused to engage with any one of the four wheels 1, 2, 3, 4, and the frame is then locked in position by a bolt in a quadrant forming part of the swing-frame. As the intermediate and driven wheels are used for each speed, the variation is entirely produced by the wheels 1, 2, 3, 4.

The teeth upon the wheels are as follows:—

Wheel No.	1	2	3	4
Number of Teeth	72	36	24	18
Speed Ratios	1/1	2/1	3/1	4/1

By following the train of mechanism, it will be seen that the screw is finally driven through a train of bevel wheels placed within a gear-box at the front of the lathe-bed, Fig. 35, Plate 25. A small handle in front of the gear-box is available for setting over a double-claw clutch, thus stopping or reversing the motion. Within the gear-box there is also a train of gears similar to Fig. 29, Plate 23, for regulating the speed of traverse, and in front of the box are handles for reversing and regulating the speed of traverse. The drive for this traverse is by belting to the gear-box from a three-speed cone on the tail end of the spindle, Fig. 35.

The feed gear applied by Messrs. Ward to their larger capstan lathes is a combination of that which is shown in Fig. 29, and that known as the Hendey-Norton. As already pointed out, the former of these gears gave three feeds and the latter twelve feeds for screw-cutting, and the same number for the automatic traverse. By a combination of the two gears, when one of them is applied to the drive for the first shaft and the other from the shaft to the leader screw, they may integrate together, thereby giving a very wide range, and thus completely dispensing with the changing of wheels in the old way. The changes applied by Ward are four pairs of meshed-gears with a sliding key on the spindle, and twelve gears upon the leader screw, which give the following variations in traverse:—

TABLE 2.

Screw-Threads cut by Change-Gear.   (Ward.)

A	4	5	6	7	8	9	10	11	12	13	14	15 per inch.
B	8	10	12	14	16	18	20	22	24	24	28	30 ,, ,,
C	16	20	24	28	32	36	40	44	48	52	56	60 ,, ,,
D	80	100	120	140	160	180	200	220	240	260	280	300 ,, ,,

The letters indicate several pairs of gears
which may be used to drive the parallel spindle.

Plate 26 shows another modification by Messrs. Lodge and Shipley of the Hendey-Norton gear, combined with a second change, as in the Ward gear; but the second change is here obtained in a different way.

It will be seen that below the headstock and within the bedplate there are two shafts, the upper one A the tumbler shaft, and the lower one B the change-gear shaft. Upon the portion of the lower one within the bed-plate, there is arranged a series of change-wheels; and into any one of these the intermediate gears carried in the sliding tumbler may be caused to mesh as required. The second series of changes is in the wheel-train, between the gear-shaft B and the leader screw C. The arrangement consists of a pair of gear-wheels keyed upon the shaft B at D, and their teeth are in the ratio of 1 to 2. A quadrant E, centered loose upon the shaft B, carries a spindle upon which two twin-gears F G are free to rotate; these each consist of two attached gears in the ratio of 1 to 2. When in position, the smallest spur-wheel at D meshes with the larger part of one of the twin-gears, and the largest spur-wheel at D meshes with the smaller part of the other twin-gear; thus their relative speeds of rotation are as 1 to 4. The final closure of this train is a sliding wheel upon the end of the leader screw, which by a handle movement can be slid into any one of four positions, meshing with any one of the wheels forming the two twin-gears; the wheels are actually meshed by raising the quadrant. By

u 2

this device four different speeds may be given to the leader screw
for each position of the tumbler on the shaft A.

The leader screw on this lathe has a keyway along its length, so
that it may act as a traverse-shaft, as in the Hendey-Norton lathe;
the gear in the apron increases in the ratio of 2·5 to 1 the cuts per
inch corresponding with the threads obtained from the screw.

Table 3 gives the threads and cuts with the combined gears :—

TABLE 3.

Threads and Feeds. (Lodge and Shipley Lathe.)

Positions of sliding gear.	Tumbler positions.											Feeds.
	1	2	3	4	5	6	7	8	9	10	11	
A	—	18	19	20	22	23	24	26	28	30	32	30 to 40 per in.
B	—	9	$9\frac{1}{2}$	10	11	$11\frac{1}{2}$	12	13	14	15	16	40 ,, 20 ,,
C	—	$4\frac{1}{2}$	$4\frac{3}{4}$	5	$5\frac{1}{2}$	$5\frac{3}{4}$	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$	8	20 ,, 10 ,,
D	2	$2\frac{1}{4}$	—	$2\frac{1}{2}$	$2\frac{3}{4}$	2	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	10 ,, 5 ,,

Another requirement of paragraph (b) is that the tool position
should be readily changeable. Therefore the question next to be
considered is, what movements of the tool are necessary, and how
may they be obtained? That the cutting tool may be brought to an
exact position, three directions of motion are essential :—firstly, in a
horizontal plane in the direction of the lathe axis; secondly, in a
horizontal plane at right angles to the lathe axis; thirdly, in a
vertical direction.

As a rule, provision is made for ready adjustment in the first two
directions by such means as the compound slide-rest; but for the
third adjustment, we are rather too familiar with the use of metal
packing strips varying in thickness. What is wanted is a quick
vertical adjustment, obtained without loose pieces of any description;
for this purpose several firms use elevating cross slide-ways, but
in most of these arrangements stiffness and rigidity are sacrificed.

Saddles.—A further consideration of the movements of the tool in the horizontal plane, both parallel to and across the axis of the lathe, opens up a number of points for discussion, such as the relative merits of the ordinary English saddle with its compound slide-rest, and of the apron saddle now being so largely fitted both in America and in this country.

As regards the English saddle, the longitudinal hand-traverse is effected by a rack-and-pinion motion without intermediate gear, and the movement so obtained is jerky and unsuitable for feeding the tool in its cut. Consequently it is used for shifting the saddle position only when the tool is not in action ; and the compound slide-rest is used for hand-feed or for fine adjustment of the tool.

As regards the apron saddle, the vertical front plate or apron has gearing within it for obtaining the various motions in an easy manner. For instance, there is gearing between the hand-wheel and the rack-and-pinion, which provides enough mechanical advantage for enabling the workman to give an easy and steady hand-traverse to the saddle with fine adjustments, thus rendering unnecessary the compound slide-rest.

These two kinds of saddles are illustrated in Plates 27 and 28.

English Saddle.—The saddle and slide-rest, Fig. 42, Plate 28, are fitted to an 8-inch sliding and screw-cutting lathe. The automatic traverse is obtained by worm-gearing from a shaft at the back of the machine. Passing through the saddle there is a light spindle, which conveys the power to the gears at the front, where there is a simple form of frictional connection to put the traverse into action. The release-nut in two halves, actuated by a cam plate, slides in a small bracket beneath the saddle.

Apron Saddle.—Two photographs of the interiors of the aprons belonging to these saddles are reproduced, one as fitted to a sliding and screw-cutting lathe, Fig. 39, Plate 27, and the other a sliding, surfacing, and screw-cutting lathe, Fig. 40. In each it will be seen that the leader screw being cut with a keyway acts in the additional capacity of a traverse-shaft, so that worms carried by the apron may slide upon the exterior of the screw-

thread. These worms drive the gearing for both longitudinal and cross traverse. In Fig. 39 the worm A meshes with the worm-wheel B, and this in turn drives wheel C and pinion D through a friction-cone, which is adjusted by a knurled nut in front of the apron. In Fig. 40 the same lettering applies to the traversing gear, and in addition there is a second worm E with gearing F, G, H for actuating the automatic surfacing feed. In both of these illustrations I is the release-nut, the details of which are shown in Fig. 22 (page 269). At the side of the apron is a handle J which slides upon the shaft K. A vertical movement of this handle either up or down causes a partial rotation of the shaft K, which by levers and link communicates with a bevel-gear train and double-claw clutch inside the headstock casting, see Fig. 41. Thus from the saddle the feed may be either checked or reversed—a very handy arrangement. There is also an automatic feed-knock-out, which is not shown in the illustrations. As already stated, the automatic feed is put into action by a friction-cone actuated by a knurled nut in front of the apron. It is assumed that this friction-gear will render it impossible for antagonistic feeds to be in action at one time; but in practice this is not so, for the fact is that, as the worm and worm-wheel are constantly in gear, the rotation of the spindle on which the worm-wheel is mounted tends to tighten the nut automatically and cause the cone to seize. If it does so while screw-cutting, as the worm-gear gives a different rate of traverse from the screw, something must break. The author has had the rack of a Hendey-Norton lathe broken three times in this way, purely by accident. The design of this apron may thus be seen to meet the requirements of paragraph (g), but it fails as far as paragraphs (e) and (h) are concerned.

To meet the requirements of (h), a neat interlocking mechanism shown in Figs. 43 and 44, Plate 28, effectually prevents the possibility of two speeds of traverse entering into action at one time. The feed-traverse is here also derived from the leader screw acting as a shaft; but, instead of a worm, a sliding sleeve with two bevel-wheels, A and B,

is mounted within the apron.   These bevels may be meshed with a third one C, from which both the longitudinal and the cross-traverse wheel-trains are driven.   The handle D, Fig. 44, works the lever E, which slides the bolt F.   On one end of the bolt is mounted a claw, which determines the position of the sleeve with the bevel-wheels ; and on the other end is a lock for the release-nut.   Thus it will be seen that, unless the bevels are both out of gear, it is impossible for the nut to close upon the leader screw, by which arrangement the requirements of (h) are fulfilled ; and by a slight further alteration (e) would also be fully satisfied.

The abolition of the compound-rest necessitates other modifications in the machine, such as cutting away the saddle to clear both the fast and loose headstocks, that the tool may get home to the centres. Further, as the fiddle-slide of the compound-rest is not available to set to an angle for turning tapers, other means must be provided if such work is to be done.

The apron saddle has been modified to suit specially the turret-saddle and cross-slide of the larger turret-lathes, where automatic traverse is essential.   Good examples of such aprons may be seen in Figs. 73 and 74, Plate 36.

On many machines the *loose headstock* is constructed in two parts, and provision is made to set over the top portion, in order to throw the centre out of line and so obtain the taper required.   In the author's opinion such a method is bad, because, in a machine where accuracy is essential, and is dependent upon the setting of centres and slides, disturbance should not be permitted when the machine has once been tested and proved accurate.   The only remaining methods of obtaining the taper are then—either to provide a means of compounding the longitudinal and cross-traverses by gearing in any desired ratio, or to use an adjustable former.   The first of these two methods is used in a few designs, but it is too complicated ; so the second seems to be the better solution of this problem.

As to the final requirement of (b).—Of the methods of fixing illustrated in Figs. 45 and 46 (page 280), the former, although most

largely used, requires the objectionable loose spanner, whereas the latter, effected by a handle and eccentric movement, may be considered more satisfactory.

Fixing of Loose Headstock.

Fig. 45.

Fig. 46.

Figs. 47, 48 and 49, show three methods of locking the centre slide; of these the last tends, when locking, to keep the slide in position, whereas the others are likely to spring it out of place.

Back-Centre Locks.

Fig. 47.

Fig. 49

Fig. 48.

Regarding Paragraph (e).—Several devices have been introduced for obtaining the double action with one motion. Two of these are illustrated in Fig. 50 (page 281), and Plate 40.

Fig. 50.—Combined Nut-release and Quick-withdraw.

(Humpage, Jacques and Pedersen.)

(*Photo, see Plate* 21.)

TURRET LATHES.

In the earlier days of engineering, large quantities of similarly turned articles were not, as now, required; therefore the kind of machine evolved at that time was one that could be used for a variety of work, and the chief object sought was general adaptability. When the need arose for the production of many similar articles at low cost, manufacturers, adapting the machine to their requirements, fitted stops to the slides, so that unskilled labour might successfully do the work of turning ; but, in order to produce a complete article, this often meant a number of chuckings. This mode of working may still be found in some factories. As an improvement on such a method the turret form of tool-holder was introduced, which developed into the now familiar turret-lathe. Thus the modern turret-lathe is purely a development of the turning lathe, brought about by the necessities of modern manufacturing. The requirements of this kind of lathe have already been set forth in paragraphs (i) to (o), and will now be further considered.

Chucks for Turret Lathes.—There seems to be some difficulty in designing a chuck which shall comply with all the requirements of paragraph (i), especially when the bar to be operated upon is over one inch in diameter. The usual thing is some form of collet chuck, as Fig. 51, together with which is combined a device for obtaining a mechanical advantage and securing a tight grip. The most favoured method of actuating collet chucks is by the combination of a pair of bell-cranks with a sliding cone. Examples of this

Collet Chucks.

Fig. 51 (Ward).

Fig. 52 (Pittler).

Fig. 53 Wolseley).

action are found in Plate 29 ; Fig. 86, Plate 42 ; Fig. 96, Plate 45 ; Fig. 101, Plate 47 ; Fig. 104, Plate 49. Other methods are by a system of wedges, by modification of the toggle-joint, and by differential screws. The combination of wedges is well exemplified in the Pittler chuck, where there are three wedges arranged in series, together with a rack-and-pinion, Fig. 52.

A powerful chuck of simple form has been adopted by the Wolseley Co., in which toggle-joints are introduced to get a tight grip, Fig. 53.

That applied by Ward, Fig. 54, to their larger turret lathes is a combination of toggles, similar to that introduced by Jones and Lamson in their flat-turret lathe.

Fig. 54.—Chuck for 9-inch Flat-Turret Lathe (Ward).
(*See Plate* 32.)

Alfred Herbert has introduced the principle of the differential-screw in his power-operated chuck, which is simple in action, requiring but little effort on the part of the operator, Fig. 55, (page 284).

The drawing of this chuck, which is a sectional plan, requires some explanation. Upon the end of the mandrel A the body of the chuck B is screwed. Its outer extremity is bored to the necessary taper to receive the split collet I; and at its inner end there is an enlarged portion cut with teeth to form a spur wheel at C, which continuously engages the pinion D mounted upon the spindle L and free to revolve thereon. Upon D a steel cone E is securely fixed. This forms part of a double-cone friction-clutch; the other parts are the spur wheel F bored right and left with internal cones, and the cone K which is securely fixed to the casing. The wheel F is firmly mounted upon the spindle L, and constrained to move longitudinally

with it, as required, by a rack-and-pinion mechanism communicating with an exterior handle. The teeth of the wheel F continuously mesh with those of a wheel G that forms part of a sleeve which is screwed upon the exterior of the chuck body B with a right-handed thread. The sleeve G is also threaded upon its exterior with a right-handed thread of slightly coarser pitch, and upon it is screwed the cap H. If

Fig. 55.—Power-operated Chuck (Herbert).

the cap H may only rotate at the same speed as the chuck body B—which it is forced to do by the constraint of the small screw M, because the latter passes through the cap into a slot cut in the body B—and also if the sleeve G is caused to revolve at a different speed, the cap H will receive a longitudinal motion in respect to B according to the difference in pitch of the screw threads upon the exterior and interior of the sleeve G. In this way the collet I is closed.

To put the chuck in operation, the handle is moved so that F is pressed to the cone E, when, as the diameter of wheel F is greater than that of D, the sleeve G will rotate faster than the body B, thus causing the collet I to be forced home by the cap H. On the other hand, if F is pressed to the stationary cone K, the sleeve is held at rest while B and H continue to revolve, and the collet is opened. With this chuck there is a greater range of motion than usual, which makes it possible to use rougher stock. Moreover for large work an exceedingly tight grip may be obtained with little effort on the part of the operator.

The chief fault of most of the collet chucks is that the actual movement of the collet is small; and moreover, as they must be moved to a given point to lock themselves, they allow of little variation in the size of the stock used. Consequently, as ordinary rolled stock of large sizes varies considerably in diameter, these chucks at times give trouble. The differential-screw chuck locks itself in any position, thus allowing greater variation in the size of the stock than the others, and therefore more nearly approaching the requirements of paragraph (i).

Stock Feed.—With regard to paragraph (j), the feeding forward of the stock quickly, yet without shock, is a matter of importance. For light stock, a cord and hanging weight are satisfactory; but, when a weighty bar of metal is to be fed forward, the inertia of the bar is too great for such an arrangement to operate quickly yet without

Fig. 56.—Stock Feed and Chuck Mechanism (Herbert).

0   5   10   15 Inches

shock, so either a hand- or a power-feed is necessary. Designs of hand-feed are shown in the illustrations, Fig. 56 (page 285) and Plate 35. To manipulate heavy stock, power-operated mechanisms have been fitted by several firms to their machines, Figs. 57 and 58 : Plate 29 ; and Fig. 63, Plate 30.

Fig. 57 shows two rollers A A, pressed against the stock by springs. These rollers are rotated by worm-gearing at B B, and a right-and-left-handed worm and a helical gear C are on each side of the feed-box. Upon the back of the box, a loose

Fig. 57.—Roller Stock-Feed (Ward).
(*See Plate 32.*)

Fig. 58.—Roller Stock-Feed (Wolseley).

ring D is fitted, having helical teeth cut upon its side E. These teeth mesh with the helical gears C upon the worm-spindles; and thus, if the ring is held stationary while the gear-box rotates with the spindle, the worms will revolve and feed the stock forward. To arrest the rotation of ring D when required, a series of indentations are cut in its circumference, into which the ends of a trip lever F may fit. To facilitate the quick action of the feed, the trip lever is operated by a rod from the handle which works the chuck; thus, immediately the chuck is released, the feed gear is set in motion.

The above feed-motion closely resembles that first introduced by Messrs. Jones and Lamson; but that shown in Fig. 58 (page 286) is different. It will be seen that rollers A A, with the worm-wheels B B, are carried in castings, and swivel around the worm-spindles C C. These spindles protrude through the back of the feed-box and have upon their protruding parts, small spur-gears D which mesh into an annular-gear E. This gear is keyed to the brake-wheel F, and that in turn rides loosely upon the boss of the gear-box. A strap surrounds the brake-wheel, and, by putting it in tension, the wheel is brought to rest, when, if the spindle is in motion carrying the gear-box with it, the rollers are caused to rotate.

Turrets.—With regard to paragraph (k) respecting the design of turrets, the author holds the opinion that the tendency in the construction of turret lathes has been to place too narrow a limit upon the possibilities of the machines. This limit is occasioned by the kind of turret, and the consequent form of tools that have been necessary, the possible length of work being too short and the size of the cut too small.

"*Hartness*" *Lathe.*—The flat-turret lathe introduced by Messrs. Jones and Lamson in 1891, correctly known as the "Hartness" flat-turret lathe, was one that was in itself a distinct change and an improvement in turret lathes for producing long work. This machine is illustrated in Plates 29 and 30. Plate 29 is a sectional elevation of the headstock, and Plate 30 shows various details of the turret and its mechanism.

From Plate 29 it is seen that there are several distinguishing features, the most important of which is the construction of the turret. A traversing carriage fits upon the bed, along which it may be traversed by hand or power. Upon the carriage there is fitted a low form of turret, which is little more than a flat plate. The details of this are shown in the various views. It will be seen that the turret centres upon a pin A, Fig. 61, connected with the carriage; but it is held in position by the gib-ring B B, which fits into a groove turned in the circumference of the turret. The locating bolt C is placed immediately below the tool position, and it is of substantial form, fitting into hard steel bushes.

For the purpose of withdrawing the locating bolt, a lever D is fulcrumed at one end upon the carriage beneath the turret, and its other end enters a recess in the locating bolt. A spiral spring beneath the bolt continually pushes it upwards, so that, to release the turret for rotation, it is merely necessary to press down the lever D. For this purpose, a circular pin E is attached to the side of D, and this is engaged by a small trigger F, carried in the end of the bar G.

For the purpose of rotation, a ratchet-ring H encircles the central boss of the turret plate, and upon its circumference are cut a number of teeth extending about half round it. Carried by the turret, in a suitable position for engaging with this ring, there is a spring-actuated bolt J which serves as a pawl. The side of the bar G is cut with teeth as a rack, so that, when it is pressed forward and releases the locking bolt, it also rotates the ratchet ring and the turret with it. For stopping the turret in position to receive the locating bolt, a spring-supported catch K engages the end of a screw L protruding through the turret plate.

The end of the bar G at M is shaped to receive a pair of spring clips N, Fig. 62, secured to an adjustable stop-rod O, and the object of this arrangement is to regulate the position at which the turret shall be caused to rotate. Thus, when traversing the turret away from the headstock, the bar G comes in contact

with the stop-rod O, the spring-catches N taking hold. A further movement first causes the bolt C to be withdrawn, and then the turret to be rotated. Now, upon reversing the movement of the carriage, the end M tends to leave O; but the catches N offer sufficient resistance to pull back the bar G, thereby returning the ratchet-ring to its original position.

The cutting traverse is effected by mechanism within the apron on the carriage front, power being obtained from a traverse-shaft. An independent traverse-stop is provided for each tool. See also Figs. 61 and 62, Plate 30. Six adjustable trip-bars are let into the top of the bed at P. Immediately above these bars and within the carriage are six triggers, fulcrumed upon a pin at Q. Each trigger is armed with a piece of bent wire R, standing upwards and coming into contact with the outer edge of the turret. Their lengths are so adjusted that normally, as they touch the turret, it holds the triggers out of contact with the bars P; but, in certain places upon the turret flange, slight depressions S, Fig. 60, are cut to receive the end of one of the wires R. In this way the particular trigger corresponding with either tool is allowed to come into action for the purpose of stopping the traverse. As the trigger engages the rod P, it causes the rod T to draw back the catch U, which in turn releases the traverse mechanism.

Without shifting the belt three speeds can be obtained at the mandrel by two sets of back-gear, which by ingenious arrangements can be brought into action without stopping the machine. Friction-cones are placed within the cone-pulley and the driven gear at W W (Plate 29), and are brought into action by the toggle-links X, over which the sleeve Y is caused to slide. There are two back-shafts, 1 and 4, placed beneath the headstock. Upon the upper 1, at one end, there is a loose sleeve 2 carrying two spur-wheels 5 and 6; and upon the other end there is a single wheel 7, which gears with the one upon the mandrel. The lower back-shaft 4 has its bearings eccentrically placed within an oscillating sleeve 8, so that according to the position

of the sleeve the wheels 9 and 10 may either mesh with the corresponding wheels 5 and 7 or be out of gear. The oscillation of the sleeve at the same time slides the claw-clutch 3, for which purpose a segmental and helical cam is placed upon the sleeve at 11. Thus the handle movement oscillating the sleeve puts the lower back-shaft 4 into or out of action, and at the same time couples up or breaks the connection by the aid of the claw-clutch 3 on the upper back-shaft 1.

The chuck and stock-feed mechanisms are both ingenious, and are similar to those shown in Fig. 54 (page 283) and Fig. 57 (page 286). The stock-feed is shown in Fig. 63, Plate 30.

The advance made by Jones and Lamson has been followed directly by Ward, whose design contains some important improvements, Fig. 64, Plate 31, and Plates 32 and 33, of which the chief is the feed-change mechanism already described. The automatic traverse is by a leader screw, which may receive forty different speeds relative to the spindle.

For the sake of the working of the automatic trip-gear, the connection of the saddle to the leader screw is made by a half-nut A (Plate 33) mounted within the saddle apron. Springs BB are provided, which tend to withdraw the half-nut away from the screw ; but the movement causing it to mesh with the screw is obtained by a small crank C connected with a handle D at the apron-front. The stop-motion and trip-gear resemble the Hartness arrangement already described. The trip-lever E (Plate 32) is moved by the stop-triggers F, which cause it to disengage a catch at G upon the spindle connected with the release-nut A. Thus, when the handle D is raised, the small crank C lifts the half-nut A, engaging it with the leader screw, and the trip-lever E engages with the catch upon the spindle between the handle and crank, and holds the nut engaged and the springs B B in tension.

A small turret is illustrated in Plate 34. The elevation shows the locating bolt and trigger, and the plan shows the automatic rotating device. It will be noted that there is only one stop for all tools in this design.

The Swedish Universal Turret-Lathe has the turret rotating about a horizontal axis, which is mounted upon a cross slide. The design is reproduced in Fig. 65, Plate 31 ; and Plate 35. With this turret there are independent stops for each tool brought into position automatically by the same movement which rotates the turret. Details of the rotating and locking mechanism are partly shown in Fig. 71.

A Hollow-Hexagonal-Turret Lathe is shown in Fig. 75, Plate 37 ; and Fig. 77, Plate 38. The turret is made hexagonal in order that tool-holders may be bolted upon the flats, the cutting tools coming close to the turret face, so that there may be little overhang. The bar being turned may pass through the hollow turret, and the possible length is thereby increased. The turret is directly mounted upon a saddle, which traverses along the lathe bed. The location bolt comes immediately below the flat of the turret carrying the tool in action. To the front of the saddle is fitted an apron, containing the mechanism for automatic traverse.

A neat detail is the automatic trip-gear, which stops the traverse for each tool independently at any place required. It consists of six bars A A laid in the bed, a piece being cut out near their ends at B ; and mounted upon a cross-rod C within the turret are six triggers D. Five of these triggers are always out of action, as only the one corresponding with the cutting tool is free to trip the traverse.

In the sectional elevation, a small rod E is seen to be placed in a vertical hole drilled through the saddle, its lower end resting upon the trigger. Its length is so adjusted that, when the flat bottom of the turret is over the hole, the small rod holds the trigger up out of action. Each trigger is provided with such a rod as this, and in the bottom of the turret are shallow recesses F F suitably situated, so that, when one of them comes over a small rod E, it leaves the corresponding trigger free to engage with the catch B in the stop-rod. The automatic traversing motion is given to the saddle from a traverse-rod by worm gearing. The worm is carried in a tumbler G, which

has an arm projecting upwards inside the apron at H; and upon the top of the arm there is a projecting piece I, which engages with a catch J on the cross-rod C. When any one of the triggers engages a stop-rod, the cross-rod C is arrested, releasing the projecting piece I, and thereby allowing the tumbler G carrying the worm to drop out of action.

The Cross-Turret Lathe shown in Fig. 76, Plate 37, and Fig. 78, Plate 38, has many novel points, the chief of which is the method of mounting the turret. The part of the lathe-bed supporting the turret saddle is set back out of the line of the spindle centre, so allowing all metal cuttings to fall clear of the ways. The stops are carried by a plate at the rear, which rotates with the turret, so as to bring them into position as the corresponding tools come into action. The rotation is effected by a rack, which, when the locking-gear is withdrawn, drops into gear with a spur-wheel mounted upon the turret-spindle. The worst feature about this turret is that the cutting pressure is wholly sustained by the locating pin.

Inclined-Turret Lathes have been designed for working upon large castings. Each of these is a new tool, in which the details of design seem to comply with all of the requirements of turret lathes, excepting paragraph (o), which does not apply to this kind of machine. The work usually turned upon these machines often necessitates the use of long overhanging tools, such as boring bars, reamers, etc. The turret is therefore set over into an inclined position, in order that these long tools may clear other parts of the machine. The lathe illustrated with details in Plate 36 and Plate 25 is a good example of the class. The headstock is provided with double friction-back-gear, giving nine different speeds of spindle with one speed of counter shaft. There are two turrets; the main one, which is inclined and is carried upon a special saddle, is more particularly intended to do the internal work upon castings; while the second turret, with four tool-places, works upon the exterior of the castings. The automatic traverse for both turrets is obtained from a splined shaft, Fig. 72, Plate 36, below the chasing-

screw.   The mechanism for giving the traverse to the second turret is shown within the apron, Fig. 73.   There are two tumblers, each with a pair of spur-wheels and a worm, swivelled about the splined shaft, with handles protruding beneath the apron to the front. By lifting one or other of the handles, either the longitudinal or the cross automatic traverse is put into action.   When the automatic stops (see the right-hand side of Fig. 73) engage the stop-rod, the retaining trigger which holds the tumbler in place is released, allowing the tumbler to drop out of action.   The mechanism for the inclined turret is within the apron illustrated in Fig. 74, and is similar in construction to that above mentioned. The trip-gear for this turret is similar to that in Fig. 77, Plate 38, already described.   A three-speed gear is shown in Fig. 35, Plate 25, by which the splined shaft can be given three speeds for each position of the belt on the speed cone at the end of the spindle; thus nine speeds of tool traverse can be given.

Turret Traverse.—Paragraph (m) requires that provision should be made for both quick and steady motions.   For light turrets a lever or a rack-and-pinion motion, with capstan handles, may be satisfactory ; but, when getting to heavier work, some other means of traversing the turret must be introduced.   For this purpose the worm-gearing in Fig. 79 (page 294) is useful when applied to heavier turrets that have hand traverse, as it enables a steady motion to be given.   For still heavier machines, power-operated traversing gear—such as those described—becomes a necessity, together with some form of automatic tripping-mechanism.   It is rarely however that a quick-motion traversing-gear is introduced for the purpose of changing the tool positions.

Cross Slide.—With regard to the requirements of paragraph (n), the cross slide there referred to is of simple construction, suitable for the lighter turret-lathes, in which all screwing may be done with dies, and the forming operations are simple.

When however the cross slide is intended to act as a chasing saddle, its construction must be modified and its length

Fig. 79.—Worm-Gearing for Turret Traverse (Herbert).

0   3   6   9   12 Inches

made greater. The chasing saddle illustrated in Plate 39 is fitted by Ward to a 9-inch capstan lathe. It has a chasing-nut of simple form, shown in Fig. 82. There is an interesting trip-motion for automatically checking the power cross-traverse. A train of gears, shown in Fig. 80, terminates at the spur-gear A, which rides loosely on the cross-traverse screw. A sleeve B is also fitted to the same screw, but a feather key prevents its rotation. The end of the sleeve is formed into a claw-clutch, so that it may mesh with claws upon the side of the spur-wheel A ; and there is a spring placed between the two, tending to keep them separated. When it is required to put the cross-traverse into action, the handle C is raised; this, through the medium of a short spindle and crank D, causes the sleeve B to slide along and make the claw-clutch engage. To retain the latter in position, there is a lever E with a hooked end, which catches into a notch upon an enlarged portion of the spindle D. To throw the cross-traverse out of action, an adjustable stop F engages the lever E, lifting the hooked end, and allowing the spring to put the clutch out of gear.

The cross-slide illustrated in Plate 40 has a special device for simultaneously withdrawing the chaser and the half-nut. It will be observed that the half-nut is attached to a

cast piece A, which, while stiffly attached to the saddle, is free to slide in a direction to and from the leader screw. A bracket on its upper part embraces the cross-traverse screw. A small vertical spindle B has an eccentric at its upper end (see also plan), and a handle C at its lower extremity. According to the way in which the handle is moved, the cast piece A may be caused to slide to or from the lathe bed, carrying with it both the half-nut and the cross-traverse screw. Thus the special requirement of paragraph (e) is fulfilled.

Leader Screws.—Paragraph (o) refers particularly to brass-working turret-lathes for making such things as brass fittings, upon which much screwing has to be done. The practice in the past has largely been to provide a rocker-shaft at the back, with a chasing arm, the traverse of which is derived from a short leader-screw on the tail-end of the spindle; but the threads so produced often vary considerably in size, owing to the spring of the arm.

Dies are often out of the question, on account of the weakness of the material worked; therefore it seems to be the best practice to use a chasing saddle with leader screw in a suitable position for a release-nut to mesh with it. By using different screws for the various pitches, the wear will be distributed over a number of screws; and moreover the screws being short are not too expensive to replace when worn. This is the practice of several firms making turret-lathes for brass work.

FULL AUTOMATIC SCREW-MACHINES.

Headstocks.—With regard to paragraph (p), the stock-feed, as used on turret-lathes, requires some degree of modification in its adaptation to the screw machine; and it usually takes the form of a tube with a spring nose-piece carrying the stock, to which movement may be given by a cam motion. The variation in spindle speed should be such as will suit different kinds of material of all sizes within the machine capacity; but there is difficulty in getting a sufficient number of changes; consequently, as a rule, two speeds only are introduced, one

suitable for turning the larger sizes, and the other for screwing
with a die It is thus evident that, if the machine is put upon brass
of a size smaller than its maximum, the economy is doubtful. A
discussion of either of the paragraphs (q) (r) (s) by itself is scarcely
possible, without touching upon matters affecting the others.

Automatic Turrets.—These are arranged on two general plans.
In one the turret has a definite and complete range of motion,
without the possibility of variation, through which it passes for each
tool-place ; and usually there is a special mechanism, with driving-
gear and cam-motion to work it.   In the other plan, the turret
motion is variable from nothing to its maximum, without any special
actuating mechanism, its movements being derived from a cam-drum,
placed on the same cam-shaft that serves the other parts of the
machine.

Each of these systems has its special advantages.   The
former, for instance, makes it possible to have a central thrust on
the turret, which is usually mounted on a horizontal axis ; and the
controlling cam is easy to set.   In the latter, there are fewer wearing
parts, and it is simple in construction ; but the cams require more
skilful setting to work at their best.   There is however the further
advantage that, as the turret does not require to go through its full
traverse for every tool-place, whether desired or not, there may be
less idle time and less wear and tear.

With regard to paragraph (s), which expresses the need for
rapid change of tool-position during the time when the tool is not
actually cutting, so that the idle time may be reduced to the shortest
possible.   In considering this point, the question naturally arises :—
What different speeds of tool motion are necessary ?   In both
the machines shown in Plates 44 and 46 there are two widely
different speeds of the cam-shaft, the slowest of which can be varied
through a given range by a cam-controlled friction-drive.   In the
machine, Fig. 84, Plate 41, and others of similar pattern, there are
two speeds of cam-shaft only, without minor variations ; but changes
in the tool-feed may be made by altering the angle of the cam-plates
on the drum.   The machine on Plate 48 provides four different

speeds without any minor changes. To get the most satisfactory work from automatic screw-machines, it is undoubtedly necessary that there should be a quick speed for change of position ; that it should be possible to change the rate of tool-feed to a reasonable extent ; and that the means of making the changes should be simple.

Of the various kinds of full automatic screw-machines several have been selected as representing good examples, and will now be described.

The Automatic Screw-Machine, Fig. 84, Plate 41, and Plates 42 and 43, is one that has a variable traverse for its turret, and the mechanism actuating it is on the whole of a simple nature. All the movements are obtained directly from the cam-shaft, which is placed in the lower part of the machine. In the general arrangement shown, the main movements, that is to say, of chuck and stock-feed and turret, are produced by cam-plates fixed upon large drums.

The drum beneath the headstock carries the plates for working the stock-feed, and also the chuck; and the drum within the frame below the turret has, around its circumference, the number of cam-plates necessary to produce the full cycle of operations of the turret. Thus for every complete revolution of the cam-shaft, an article is completed. The plates immediately under the main driving pulleys have upon them the cams for controlling the belt-forks connected with the main-spindle drive. The disc below the cross-slide has upon its two faces the cams to work the cross-slide through the medium of levers. The cam-shaft drive is attached to the end of the machine, and consists of worm-gear mechanism. The worm-wheel is keyed to the cam-shaft, and the worm is mounted upon a cross-spindle which has a pair of pulleys upon it for a belt drive. A disc upon the cam-shaft at the extreme right carries the cams to control the striking-fork connected with the belt-drive for the worm-gear.

The headstock is illustrated in detail in Fig. 86, Plate 42. The spindle runs in halved phosphor-bronze parallel bearings,

and within it are the chuck-tube and the stock-feed tube. The chuck is of the pull-in collet kind, and is manipulated by the usual cone and bell-crank mechanism. To insure the ready opening of the chuck, a spiral spring is introduced. A projecting tail-guide is bolted on the back of the headstock, to support the riders which transmit motion from the cam-drum to the chuck and stock-feed tube. The belt-shifting mechanism is also shown in Fig. 86, Plate 42. The striking forks are controlled by a sliding rod, which receives its motion from the cam-disc below. The details of the turret are reproduced in Fig. 87.

The driving mechanism for the cam-shaft has two speeds only, one for the rapid motions required when changing the tool positions, and the other for the slower cutting speeds. It is of course necessary that the cutting speed should be variable; but the smaller variations, apart from the large change, are obtained by an alteration of the angles of the cam-plates, fitted upon the drum of the two pulleys A and B, Fig. 88, Plate 43. A is keyed to the worm-shaft; it is made hollow, and within its interior there is fitted a small spur-wheel upon the nave. The pulley B is loosely fitted upon a sleeve, which in turn is loosely fitted upon the worm-spindle. The sleeve has a spur-wheel at one end, similar to that within the wheel A, but differing slightly in the number of teeth; and upon the other end of the sleeve is keyed a ratchet-wheel. A stud fixed to the web of wheel B carries a small pinion, which meshes with both the spur-wheels within the pulleys A and B. When the belt is upon pulley A, the worm is directly driven with a fast motion; and, when the belt is moved over upon B, the epicyclic train of gearing is brought into action, reducing the speed as required. The belt speed being rather high, it follows that, when the belt is quickly moved over from A to B, A would tend to act as a small fly-wheel and throw considerable stress upon the gearing. A brake is therefore provided, which falls into action as the belt is moved, and checks the rotation of pulley A.

The method of setting out the cams for use on this machine is shown in Fig. 91, Plate 43, in which also is an expanded view

of the drum that works the turret.   At I, Fig. 91, circles are drawn showing the positions of the friction-roller, between which the operation of turning, and also the unlocking and the rotation of the turret, may take place.   These roller positions are a guide to the setting of the cam-plates.   The words " fast feed " and " slow feed " indicate which of the main feed speeds is in action, that is to say, whether the belt is on pulley A or B.   The number of cuts per inch taken by the tool is regulated by a variation in the cam-plate angles.   A diagram is set out in Fig. 89, which forms a key for the cam-plate angles, for cuts ranging from 100 to 800 per inch.   It will be noted that during the changes of position, when the tools are not cutting, the maximum speed of movement is given, and is obtained by pitching the cam-plates to a slope of one in two.

Fig. 92 is the drum which actuates the chuck and stock-feed ; and as the cam-plates upon it give as quick a movement as is desirable, they are rarely changed.   The plate J determines the length of stock fed forward ; as it is only necessary to change its angle, it is pivoted at one end and bolted to the drum through a slot at the other.

Fig. 90 shows the cam-plates for working the cross-slide.

The Automatic Screw-Machine, Plates 44 and 45, is one of the kind which has a definite traverse of turret.   The traverse itself is obtained from a cam mounted upon the same axis as the turret, and there is special mechanism to drive it.   Plate 44 shows the general elevation and plan, and Fig. 94, Plate 45, gives details of the cam-driving mechanism.   Fig. 95 shows the detail of the turret with its locking and traversing gear, and Fig. 96 is the sectional plan of the headstock.   The main cam-shaft is placed on the same level as the spindle, and at the rear of the machine.

A is a segmental cam which controls the chuck.   B B are two small cams which control the striking fork that determines the position of the belt for driving the spindle.   C is a drum upon which cam-plates may be mounted, to regulate the cross slide through the medium of a bell-crank.   The cam D is of

peculiar shape, and controls the stock-feed through the rod
E. F is a combination of a spur-wheel and cam-drum, the
cam-shaft receiving its motion from the spur-wheel portion.
The drum part is slotted, to allow for the adjustment of a
series of plates which form the cam-shape that controls the
speed of the tool-feed and cam-shaft. On the inner side of the
spur-wheel, there are some adjustable tappets G, whose function
is to cause the change-over from the quick speed used during
the change of tool position, to the slow speed required when
cutting.

Fig. 94 is a transverse section upon the line H H, which passes
through the centre of the driving-shaft. I is a flanged driving
pulley, firmly keyed to a sleeve which passes through the
adjacent bearing and carries upon its outer extremity a friction-
disc. A second friction-disc J is mounted upon a parallel shaft
below, at the inner end of which is the first gear of a spur-wheel
train L. The driving pulley I runs at a constant speed, and the
friction-disc connected with it drives the second friction-disc J
through the medium of a movable horizontal friction-wheel K.
The position of K is determined by the shape of the segmental
cam F, and, according as K is raised or lowered, the disc J revolves
at a slower or faster speed. The spur-wheel L is free to
revolve upon the fixed sleeve M. A second sleeve N is driven
at a slow speed through the epicyclic train of gearing carried
upon L. Keyed upon the worm-shaft is the sliding part of a
double-claw clutch, and, according to its position, the worm-
shaft may take its motion from either I or N, the speeds of
which are vastly different. Thus, when I drives the worm
directly through the clutch, the quick motion for changing the
tools is obtained ; and, on the other hand, when I is coupled to
N, the speed of motion has been regulated by the friction-gear
and reduced by the epicyclic train, so that the slow speed for
cutting is now obtained.

The worm-wheel O, as seen in Fig. 95, is mounted upon a
sleeve P, which runs loose upon the bar that forms the turret-
axis. Keyed to the same sleeve is a spur-wheel Q, which drives

the cam R through the medium of a broad intermediate pinion mounted in the frame below, and of another spur-wheel that forms part of R. The friction-roller S, attached to the machine frame below, fits into the cam-groove; therefore the cam, as it rotates, must move longitudinally, carrying with it the turret T and its axle. The locking-bolt U passes up through the metal of the frame from below, where there is a withdrawing lever pressed upwards by a spring to keep the bolt in position for locking the turret. The bolt is withdrawn by the plug-rod V, which is pressed downwards upon the withdrawing lever by a cam-projection on the cam-sleeve R. The rod V acts when the turret is in its rearmost position ready for rotation, the rod W then acting as a driver to revolve the turret. The extreme end of the sleeve P is cut to form a pinion at P^1, which drives the spur-wheel on the main cam-shaft at the back.

But little description of the headstock, Fig. 96, is necessary, as the arrangement of the chuck and stock-feed is of the usual kind. For the drive there are three pulleys upon a back-shaft; the extreme left one gives a quick backward motion to the spindle through three spur-gears; the middle one runs loose; and the one upon the right gives a slower forward motion through two gears only. This method of driving was no doubt applied before the time of self-opening screw-dies; but at the present day it is found better to sacrifice the quick reverse-motion, in order to obtain a second forward speed; and the two forward speeds are so proportioned that one is suitable for turning and the other for screwing.

Further details of the friction-gear are shown in Fig. 97. The arm X of the bell-crank X Y is virtually a segment of a spur-wheel meshing with the jockey Z, which carries the intermediate friction-wheel K; and the arm Y has a friction-roller upon it, in connection with the cam F, Plate 44.

The Automatic Screw-Machine, Fig. 85, Plate 41 and Plate 46, is one that must be reckoned of the same class as that in Plate 44, since it has a fixed forward traverse of the turret. Fig. 99, Plate 47,

shows details of the driving mechanism for the tool-feed and for the cam-shaft. Fig. 100 is a section taken vertically through the turret, and shows its locking and actuating gear. Details of the headstock are shown in Fig. 101.

The drive for the tool-feed and for the cam-shaft is by the aid of friction mechanism as in the machine last described.

A short spindle, mounted upon a bracket at the rear of the machine, has upon one end a flanged pulley for the belt-drive, and upon the other a small friction-wheel. A pair of friction-discs A A, Fig. 99, are centred upon a pair of vertical arms B B, which are hinged upon a carriage sliding along shaft C. The position of the carriage controls the speed of feed, and is itself regulated by the cam D situated below, Fig. 100, through the levers E E, shown also in Plate 46. Another small friction-wheel F, facing the first, is mounted upon a spindle which passes through the bevel-gear box G, Fig. 99, where there is a train of three bevel-wheels in gear. The first H runs loose upon the spindle; the second I is keyed upon the worm-shaft; and the third J forms part of a sleeve which passes out through the other end of the gear box. A double-claw clutch slides on the spindle between the two bevel-gears H and J, and when it gears with H the drive is direct to the worm, and gives the fast speed for changing the tool positions. But if the clutch is moved to the other side, a secondary spindle K is coupled up to the first spindle, and the motion must pass through an epicyclic train of gearing contained within the revolving hood L, which rotates with the spindle K, and drives the sleeve that forms part of the bevel wheel J. The speed is thus brought down to the slow motion necessary for the tool when cutting. The position of the claw-clutch is regulated by tappets adjusted on the circumference of the disc M, which act upon the levers and connections N N.

The cam O, which directly feeds the turret forward, is placed within the turret interior, Fig. 100. The turret is withdrawn by a spiral spring at its centre, and the function of the cam is merely to press the turret forward. The worm-wheel that

receives its drive from the friction-gearing is keyed directly upon the shank of the cam, and to it there is fixed a spur-wheel P, which in turn drives a gear-train coupled to the main cam-shaft. The turret locking-bolt Q is placed within the machine frame, and is continually pressed upwards by a spiral spring. When it is necessary for it to be withdrawn, a projection within the cam-wheel D engages with a pin upon the lower end of the bolt.

The striking forks for the spindle-drive are fulcrumed upon the machine frame below the headstock, and their positions are controlled from the cam-discs R R, Fig. 98. There are two cross-slides, which are moved by simple levers worked from a cam S beneath. A large cam-drum T has movable plates upon it, for actuating the chuck and stock-feed. In this machine there is no provision for driving the spindle backwards; but it has instead a simple two-speed belt-drive. The way in which this is obtained is worthy of note. Upon the counter-shaft are placed side by side two pulleys of different diameters, and at the headstock there are three pulleys, of which the two exterior are loose, and the middle broad one acts as the driver, Fig. 101. Although concentric with the spindle, these pulleys do not take their bearing upon it, but fit upon the exterior of the spindle-bushes, which are made of solid cast-iron of considerable length, and are tightly fitted into the poppets, projecting inwards towards each other until they nearly meet. Between them there is keyed upon the spindle a steel ring, through which the spindle is driven by a long screw passing radially through the middle pulley into the ring. It will thus be seen that the bearings are excellently formed to withstand wear, as they are much above the usual length.

The Automatic Screw-Machine, Plates 48 and 49, was originally designed for use in the production of small turned and screwed brass articles. It was intended for use in a factory where floor space was an important consideration; thus it was made of very compact form, the whole machine requiring but little more room than the headstock of a medium-sized lathe.

The spindle A, Fig. 104, Plate 49, is of usual form, with a pull-in collet-chuck and automatic stock-feed. It is driven from a shaft B at its side by a pair of spur-wheels. Immediately below the spindle is a strong mandrel C which rotates in large bearings, having the turret D D mounted upon it. By the side of the turret-mandrel is the cam-shaft E, carrying the various cams which traverse and rotate the turret and actuate the stock-feed and the chuck. The cam-shaft makes one revolution for each traversing motion of the turret, that is to say, for each tool-place. As therefore the cams for actuating the chuck and the stock-feed are on the same shaft, and come into action only once or perhaps twice in the revolution of the turret, it is necessary to have some means of detaching the various cams from the cam-shaft, when it is desired that they should remain stationary. This is provided for by mounting them loosely upon the shaft, and temporarily attaching them to it by means of a simple form of clutch when they are to rotate. The clutch is of interest, as it is an important feature in the machine. On the end of the cam 1, Fig. 107 (page 305), is fixed a ring 2, overhanging a portion of the clutch; and at one place in its circumference there is a hole, into which engages a bolt 3, carried in the overhung portion of the clutch. In the illustration the bolt is dotted in behind a cross slide 4, of which the particular function is to disengage the bolt when required. Two springs 5 5 constrain the slide 4 to move to the right into the position shown in the drawing, so that its curved end 6 projects beyond the clutch-disc. At 7 the slide has an inclined slot, which meshes with a pin upon the bolt 3. Should the projecting end of the slide encounter an obstruction at any point in the revolution of the clutch and cam, it is pressed inwards, and withdraws the bolt from the hole in the ring 2. The cam 1 so released then remains stationary, while the clutch makes a complete revolution, when, if the obstruction has been removed, the bolt will again engage in the hole. By maintaining the obstruction however, the clutch continues to revolve independently of the cam until the obstruction is

Vertical-Turret Automatic Screw-Machine (Brockie).

(See Plates 48 and 49.)

Fig. 107.—Detail of Cam-clutch.

removed. Thus, by providing obstructions actuated mechanically, the cams may be brought into action or kept at rest as and when desired.

Below and behind the cam-shaft E is another shaft F, Fig. 103, on which are mounted a number of discs carrying adjustable projecting plates. The plates act as the obstructions required for regulating the operation of the clutches on the cam-shaft. The shaft F is called a mechanical commutator, and it is rotated by a ratchet mechanism worked by a double-lobe cam on the cam-shaft E, which gives it two forward motions for each revolution of the cam-shaft.

Apart from the cams upon it, the cam-shaft itself rotates continuously in one direction, being driven through a speeding gear which may drive it at any one of four speeds. The mechanical commutator F has the additional function of controlling the speeding gear. In the plan, Fig. 106, the commutator is at F, and the worm which drives the cam-shaft is at G. The remainder of the mechanism there shown is the

Y

speeding gear. The shaft H is driven by belting from the shaft B, Fig. 104, and has fixed on it two grooved friction-wheels I J ; it also carries a loose sleeve L, and a spur-wheel K with a roller-clutch in its interior. M is a jointed shaft built up in five lengths, three of which are carried by swinging brackets N N N, and each is coupled to its neighbour by a universal joint. The three lengths carried by the swinging brackets have each a grooved friction-wheel to mesh with either I or J or with a friction-wheel on the sleeve L. The slowest speed is through K, which is always in action when the others are disengaged ; but, when either of the others comes into operation, the roller-clutch allows K to be overrun. Each of the other speeds is brought into gear by projecting plates O O O on the mechanical commutator F. These act through the medium of a simple lever and coupling-rod upon the swing brackets N N N, and press the friction-wheels together as required. The gears on the whole run at high speeds, which are reduced for the cam-shaft E by two worm-wheel drives at P and G ; for the quick motion required when the tool is not cutting, the gear at L is used, which is a means of going round the worm-wheel gearing at P. The cross-shaft R is driven by L through a pair of helical wheels at S ; and in order that the two gears at S and P may not scotch each other, the worm-wheel at P and the helical wheel at S upon the shaft R each have roller-clutches in their interior.

Instead of the cross slide usually fitted in automatic screw-machines for profile-turning and cutting off, this machine has a rocking-shaft T, Fig. 104, above the spindle, with two arms U U, Fig. 105, on its front end. The oscillating motion is given to them by a connecting-rod V from a crank-disc upon the end of the cam-shaft E ; and the crank-disc is caused to rotate with the cam-shaft when required, by a clutch mechanism similar to that used for the other cams.

Four other kinds of Automatic Screw-Machines are illustrated on Plates 50 and 51.

The "Spencer" Machine, Fig. 108, Plate 50, is provided with a double turret and two spindles. This is intended to do work which other machines can do only in two series of operations. When work which has been operated upon in the usual manner is about to be cut off, the second spindle with its chuck comes forward and grips it, and then withdraws into the position shown. A further series of tools upon a second turret can now be brought into operation, to finish off the rear end of the work as may be desired. In this way it is possible to finish completely upon machine work which requires a screwing operation at each end.

The Four-Spindle Automatic Screw-Machine illustrated in Fig. 109, Plate 50, has several novel features. Four bars of stock are acted upon simultaneously by different tools, which represent the several operations in producing a piece of work. The tool support does not revolve in the same way as an ordinary turret, so as to place the tools in line with the spindles; but this particular function is transferred to the headstock.

> The work-spindles are carried in a drum contained in the portion which corresponds to the headstock; and the drum is periodically rotated through a quarter of a revolution to bring the spindles into their new positions before the tools. The spindles do not rotate continuously, being driven through collet chucks which embrace them; the releasing of the collets allows the spindles to remain stationary. The tools are mounted on spindles which are supported in the tool-holder, and each of the tool-spindles may also be caused to rotate or be kept stationary in a similar way to the work-spindles. Their speed of rotation however is slower than that of the work-spindles, and is in the same direction. The tool-holder, containing all of the tool-spindles, receives a traversing motion from the cam-shaft below. It will thus be seen that a cutting action may be given by
>
> (a) Work-spindle rotating, and tool-spindle sliding only; this gives a quick cutting speed.
>
> (b) Work-spindle stationary, and tool-spindle both rotating and sliding; this results in a medium cutting speed.
>
> (c) Work-spindle revolving, and tool-spindle also revolving

and traversing; the cutting speed is then the difference between the two speeds, and is consequently slower than the others.

The direction of rotation is such that the tool-spindle carries the threading dies or taps for screw-cutting, and the screwing takes place while the work-spindle is at a standstill. When the screwing is complete, the machine is not reversed, but the work-spindle starts revolving in the same direction as the tool-spindle, and thereby runs the work out of the die or off the tap.

An illustration of an Automatic Screw-Machine now being made in Germany is shown in Fig. 110, Plate 51; and Fig. 111 shows the "Hartford" Hopper-Feed Automatic Screw-Machine. Both these machines closely resemble that already described and shown in Fig. 84, Plate 41, and in Plates 42 and 43; they need not therefore be explained in more complete detail.

It will be readily acknowledged that the capstan lathe is an evolution from the ordinary lathe, and that the full automatic machine is a continuation of the same process. Moreover inasmuch as the capstan lathe developed from small to large sizes, and its range of action increased by the modification of the capstan with the method of traversing it, so may it be expected that the full automatic machine will develop to do work of much increased size.

In conclusion, the author desires to state that it has been his effort so to compile this Paper as to bring out the various points of importance in the construction of light lathes and screw machines in such a way that they may readily be grasped for discussion. He also ventures to reiterate the hope that the discussion may hinge upon the details of design, and that suggestions for improvements and future development may be put forward.

The Paper is illustrated by 32 Plates, Nos. 20–51, and by 39 Figs. in the letterpress.

Discussion on 15th February 1901. ·

The PRESIDENT said he was sure the Members would agree with him that the Institution was indebted to Mr. Ashford for a most valuable addition to its Proceedings. The Paper represented an immense amount of work, and opened up a vast number of points for discussion, and he hoped therefore it would be thoroughly discussed. He would ask the Members to accord to Mr. Ashford a hearty vote of thanks for the trouble he had taken in preparing the Paper.

Mr. ASHFORD said that perhaps some slight apology was due from him to the members for his having prepared this Paper, inasmuch as he was not engaged in the manufacture of lathes and screw machines. He felt that no doubt there were many experts actively engaged in the trade who could have done better justice to the subject, although no doubt it would have been difficult for them to give unbiassed opinions. The object had been to treat the subject from an impartial standpoint, presenting details of various machines of both English and foreign manufacture, for discussion, that the opinions of both makers and users might be expressed to their mutual advantage. The class of machinery having undergone many developments during the past ten years, the author felt that he would be justified in bringing the subject before the Institution in order that the engineering world might be aided by the expression of definite opinions, during the discussion, as to the value of these new machines in manufacturing establishments. With a view to drawing together information from all sources, the initial procedure was to communicate with a large number of machine-tool makers, both in this country and abroad, expressing the author's intention to prepare this Paper ; defining its scope and asking for information and assistance. As a result many detailed drawings of machines and other particulars were furnished. This effort was further supplemented by a journey in the provinces, where many establishments were visited and valuable information obtained. The many particulars and details of machines placed at his disposal

(Mr. Ashford.)

made the work of selection by the author extremely difficult. The chief difficulty from first to last was to decide what to leave out and what to put in, considering the necessity for keeping the length of the Paper and the number of illustrations within reasonable limits. It must be said that many illustrations of machines and details, which were available and had been left out, were omitted, not because there was not a want of merit, but purely from lack of room.

An effort had been made to retain a line of argument throughout the Paper, and at the same time to insert descriptions of various machine details, the argument and matter being so paragraphed and split up, that it could be easily referred to by members in discussion. In conclusion, attention was drawn to a large number of specimens of work made on the machines described and also to two automatic screw-machines—the Herbert and the Wolseley—which together with a number of tools were exhibited. There should have been four machines on view, but unfortunately one, the Acme screw machine, when being loaded into a van, slipped from its slings and was broken. The unfortunate illness of Mr. Endsworth, the manager of the Cleveland Screw Machine Co., prevented him from sending one of that company's machines for exhibition at the meeting, as had been intended.

He expressed his indebtedness to the firms who had aided him by exhibiting specimens at the meeting and furnishing him with details of their machines.

Mr. J. HARTLEY WICKSTEED, Vice-President, congratulated the author upon the production of his Paper, which he thought was quite an achievement. It showed great pluck on the author's part to bring his mind to bear upon a subject on which he was not perforce engaged as a manufacturer, and master the principles of the automatic machines, which he said in two places in his Paper were a development of the turret rest, or a modified turret-lathe.

The key to the automatic machine was the introduction of another belt for the movement of the turrets. In the turret lathe, as soon as the turret came up to the stop and disengaged the feed gear, it was moved back by the attendant; then another stop turned

round the turret to a new place, and engaged the new feed-gear, so that it was made into an automatic machine by having a continuous-running pulley driven by a belt, separate from the belt which drove the headstock and the spindle of the machine. Then when the turret came up to the stop, it not only disengaged the feed gear, but it put a catch into the continuous-running pulley, which acted exactly as an attendant would act if he were there. That made the whole thing possible; whereas on a large scale if the automatic movement of the turret were effected by catches and tumblers, tripped and disengaged by the revolving spindle itself, it would be almost hopeless.

The author said that he wished the discussion to be directed to practical details as far as possible, with a view to suggesting improvements. He would therefore call attention to Plate 23. In Fig. 29, a system of change feed-motion was shown, in which a sliding bar in the centre of the shaft brought a cross-cotter into the keyways of whichever of the three wheels one wished to engage. In Fig. 30 another system was shown in which the three changing wheels were all keyed fast upon one sliding socket, and were slid into gear with the wheels which it was proposed to drive either at a medium, a quick, or a slow speed. Fig. 30 had great advantages from a mechanical point of view over Fig. 29, because there were no loose wheels revolving upon a shaft which required to be greased. All the wheels were keyed fast. The three wheels upon the driving-shaft were all keyed permanently fast; the driving shaft only revolved in its bearings. The other wheels were all keyed fast to the same socket, but the socket did not revolve upon the shaft which drove it, but simply slid upon it. He thought there was a mistake in the arrangement of those three wheels as shown on the drawing. Suppose the medium gear at the right-hand side were engaged, and a slow speed were wanted, the gear would have to be pushed through the fast speed before the slow speed were reached. Similarly if one were working at the slow speed and wanted the medium speed, the gear would have to be pushed through the fast speed before the medium speed could be reached. It was just as easy to put the wheel for the medium speed in the middle, the slow at one end, and the fast at the other.

(Mr. J. Hartley Wicksteed.)

In Fig. 31, where there were 12 wheels on one shaft, that was good from his point of view, because all the wheels were keyed fast upon the shaft. The intermediate driver was swung down, and up into any of those wheels. He should imagine that if those wheels were engaged upon the sliding-key principle, it would not be many years at any rate before some one of the 12 might get seizing and grinding, and perhaps wobbling a little.

It seemed rather a shame to go too much into detail, and to challenge a little drawing in the middle of the text, but there was such an extremely bad loose headstock shown in Fig. 45 (page 280) that he hoped it would be amended before it was permanently recorded in the Proceedings. It looked as if it had come out of a little text book of fifty years ago. The fact was, that if anybody ever tried to take a strong cut on an old-fashioned lathe, the first thing ascertained was that the poppet-head lifted, because in the old-fashioned lathe the bolt was put in the middle of the poppet-head, just as in Fig. 45 ; whereas the bolt ought to be as close up to the front of the head as it could be, more like what was shown in the next figure, Fig. 46. The poppet-head also would be better if it had a nose on the front of it, which was generally required in the case of a slide-lathe.

The author suggested (page 277) that compound slide-rests could be done away with, if only the mechanism for moving the saddle along had sufficient mechanical advantage to move it along with a fine adjustment for adjusting the tool. That he gathered to be the author's idea, where he was speaking of small slide- and screw-cutting lathes. But that could not be carried out, for this reason, that when the screw was engaged the tool might need to be adjusted ; and when the screw was engaged, however fine the arrangement was for travelling the saddle, the tool could not be adjusted by means of the saddle while it was engaged to the leading screw. The tool must be adjusted upon a separate rest ; and he thought for general purposes it was necessary for the tool to be held not only upon a saddle which had longitudinal motion, and also upon a cross slide which had a transverse motion, but in addition upon a rest-gauntree which had a longitudinal motion parallel with the bed, upon which

the tool could be adjusted without disengaging the saddle from the leading screw. This rest-gauntree should also be capable of swivelling to enable the operator to do taper turning without even a former. He believed the author had not mentioned this alternative means of doing taper turning. One was not obliged to do it by setting over the loose centre, nor yet by means of a former; but if one had the rest-gauntree it could be put to an angle, and the work done very well indeed.

The author, in analysing the action of outside screws, mentioned the cross-binding action which might be put upon the saddle. If that was found a difficulty in practice, it could easily be overcome by making the guides of the beds square instead of V-shaped. The saddle would not bind upon square guides. There had to be two slips, one to take up horizontally, and the other to take up vertically. That was done very much in large machines, and he had no doubt, if there was any difficulty in the cross-binding, it would get over it.

The author made use of the expression (page 259), "That the changes in themselves are great may be realised, when we consider to what an extent milling processes have supplanted shaping and slotting." The Paper was not upon milling, and he did not know whether he should be right in touching upon the subject. He was rather at issue with the contention that milling processes had supplanted shaping and slotting. Milling of course was very good in its place, but it had certain limitations. It was well adapted for taking off an equal quantity of work—for instance, such things as had been forged in dies—and it was also good for taking off clean and moderately soft material. But if one had a large quantity of stuff to take off, and irregular in amount, perhaps also hard and gritty, in his own practice he had found that slotting had supplanted milling. Fig. 112 was an instance of the crank-web of a built-up marine crankshaft. The one under discussion was about 5 feet long. There was a hole bored for the crank-pin at A, and a hole bored for the crank-shaft at B. The forging was somewhat

Fig. 112.

(Mr. J. Hartley Wicksteed.)

rough, made of scrap-iron, and had a good deal of surplus stuff upon it.
When the shape of the crank was set out, there were places where very
little had to come off. The forging was about 12 or 14 inches thick.
The dotted line was something like the shape of the thing after it
had been planed on the two faces. It had to be shaped into a
symmetrical profile, and the profile to which it ought to be shaped
was as shown by the full line round at each end, and joined by two
internal curves. An attempt had been made to mill that outline,
but it had not been very successful. When it was required to mill
it, the first thing was to saw off the thick rind with a ribbon-saw.
It was not possible to make the ribbon-saw leave the finished crank,
nor could the ribbon-saw be run quite close up to the finished line.
It was therefore sawn round within one-eighth of an inch of the
finished line, and then it was milled. If, instead of that, the forging,
or two such forgings one on the top of the other, were put on to a
powerful slotting-machine with a downward cutting tool which would
cut thick or thin before it, no matter whether half an inch or three
inches were to come off, the tool if strong would do it. It would
slice off thick and thin before it as the table fed round on the
centres. There was another upward cutting tool which took off
the last eighth of an inch on the upstroke—what was left by
the last tool; it cleaned up the corners and the edges. It was
possible to go round two crank-webs once, and then pull them
off the machine with a bright, clean, perfect finish, the operation
being performed in the same time that the ribbon-saw would cut and
go round it preparatory to milling. In that way the whole process
and the whole time spent in the milling was entirely supplanted by
slotting.

Mr. H. F. DONALDSON said that in his opinion the Paper was of
the utmost value, not only to the Institution as an institution, but to
every member who had to use tools; and as its contents would no
doubt go much beyond the limits of the Institution, it would be of
value to the country at large. The country was in want of knowledge
on the subject of modern tools, in a great many directions. The
Paper touched some of those directions in a clear and concise

way, and it gave the user some knowledge in his own office of the operations which individual machines were supposed to carry out, and which would assist him in choosing machines for further examination. The author had asked the members to confine the discussion to points which, from the users' point of view, it would be impolitic for him to follow. As a buyer and a user, the opinions which he formed would appear from the purchases made, and it would be ill-judged if he expressed in words a preference for any type of machine. All the types of machines, so far as he had heard their points mentioned, were good in some directions. Some had larger scope than others, but he did not propose to adjudicate between them. Mr. Wicksteed had made some remarks as to the origin of the automatic machine. It seemed to him that its origin was due to a want having arisen. As would always be the case with engineers, if anything was wanted or if progress had to be made, engineers would find a way through. Speaking not with regard to the machines themselves but to the reasons for their existence, he thought one would have to look across the water to the United States for them. The introduction of automatic machines was due to the high cost of labour and the absolute necessity of getting work done, without having to expend more in wages than was necessary, and to allow of the manufacturer having the possibility of adopting more or less unskilled labour in many productions. However the subject was considered, the amount of skilled labour available was always limited, and always would be so. The result, which their cousins in the United States aimed at, was to get as large and as cheap a production as possible. That was what Englishmen aimed at too, and if they were to do it in the same way as the Americans, it meant that they would have to specialise in the same way. English machines hitherto had attained the character of a very high standard of excellence, but they required brains not only to produce but also to work them. With the automatic machine, brains were required to start it, but after that the attendance did not need to be of the same calibre as was required at the start ; the watching, the keeping in order, and the feeding of the machine could be done by a less expensive man.

(Mr. H. F. Donaldson.)

He did not think he ought to deal at all on the particular line of discussion which the author desired, and which he hoped might be gained by the assistance of other members, but there were one or two points to which he would like to refer. The author mentioned (page 259) the necessity for new organisation. He was not quite clear to which he intended to give the preference: whether the new organisation came first and then the machines, or the machines first and then the new organisation. He thought both were wanted in many places, and he hoped they would be obtained by degrees. He entirely agreed with the author that modernisation was wanted.

Referring to the point (r, page 263) he was also in agreement with the author that it was most undesirable, whatever the type of the machine, that it should be restricted in its capacity. As he understood it, if a machine was supplied to travel over a certain distance—that is, to work over a certain number of inches—and it was put to do a less number of inches work, that machine was losing something, and the owner was also making a loss. Therefore such a design would not be the most suitable except for a particular job which exactly suited its dimensions. If new machines were to be obtained and were to be specialised to that extent, then those machines must do nothing beyond the particular job for which they were designed. The English practice at present had not reached that point. The author (page 263) expressed a preference for the use of self-opening dies as giving a greater capacity to a machine. If this applied to an automatic machine he, generally speaking, agreed; but he would be very sorry to see the possibility of working the first type of dies altogether omitted. There were occasions in his experience where it was found that the opening die did not give such good results as the reversing die. With regard to spindles, the author (page 264) seemed to separate material from dimension. His personal view was that hard steel and phosphor bronze formed the best type, but they must in any case have sufficient surface; the surface must not be restricted whatever the material was.

With regard to V-beds, the old English practice, according to his recollection, was that all lathes were made with a V-bed. They had been dropped in England, whether on account of the " give " in

the saddle he was unable to say, though there were current designs
in which they appeared to be returning again. Practically all the
American machines he had seen were supplied with a V, and ocular
demonstration had shown that those machines, whether on that
account or for some other reason, were much more easily handled
and moved more lightly than the ordinary English type. No special
deduction seemed to be drawn by the author from his reference
(page 295) to short pieces of leader screw:—" By using different
screws for the various pitches, the wear will be distributed over a
number of screws." He was not clear whether these pieces were
hollow or solid. The only maker he had come across who adopted,
what those words would fit with, hollow screws was Messrs. Humpage,
Jacques, and Pedersen.

Mr. ASHFORD said that Messrs. Archdale supplied loose ones also.

Mr. DONALDSON said he was not aware of that ; but it seemed to
be a good step, because it must enable greater accuracy to be retained
for a longer time at a cheaper price. The piece of screw being only
used which was wanted, and the spindle being unchanged, the
insertion of a new piece of screw made no change in alignment of
machine. Dealing with full automatic machines, the author made a
remark that unless the machine was supplied with the right size of
material to work upon—that is, if the machine was put to work on
productions a size smaller than its maximum—the economy was
doubtful. If the rest of the machine was left alone, there was
absolutely no doubt that it was not economical. From a small piece
of regular work carried out the other day, but used as a basis of
experiment, it was found that the difference in the production of a
particular article on one machine, where it was the largest size the
machine would take, and also on another machine where it was only
about three-fourths or two-thirds of the full capacity of the machine,
was about 40 per cent. in time. There could be no question therefore
that, unless the larger machine was modified or the piece of work
to be done upon that machine could be adapted to correct this loss, it
had better not be put on the larger automatic at all. It might be of

(Mr. H. F. Donaldson.)

some assistance to gentlemen, who were using or thinking of using automatic machines, to know that recently in working smaller articles on a machine having larger capacity in place of a loss by the use of the larger machines on the small article, the loss had been corrected entirely, so that practically a saving on the other side was attained by camming up the machine double so as to turn out two articles per cycle of the cam drum. In that case the modification of the machine was merely the duplication of the cam. The capacity of the machine was not doubled, but was increased by about 50 per cent., and the loss which would have resulted from using a machine of too great capacity on a small piece of work was got over.

Mr. HERBERT AUSTIN, of the Wolseley Machine Tool Co., drew attention to the fact that many of the Papers read at the meetings were too comprehensive to admit of a proper discussion on the points with which they dealt. The subject of the automatic screw-machine was too large a one to thoroughly discuss in one evening or even two evenings. The author said (f, page 261), "When taper turning, it should not be necessary to disturb the alignment of the tailstock, or the set of the rest." His firm had made machine tools with fixed tailstocks and also tailstocks that could be set over, and although the utmost care had been used in the fixed tailstock, it had always been found much better to arrange it so that it could have an adjustment. It did not matter how careful one was in the alignment; it might be perfectly true if 2 feet were being turned, but when 6 inches were being turned, either from the spring of the rest or from the impossibility of getting all three points in line—the bed and the two points of the head and tailstock—there was a difficulty in getting correct work out of it. He did not think there was any disadvantage in having the tailstock so arranged that the alignment could be set to suit the work being done. He had never found the slightest difficulty in it. Most modern lathes had an adjustment, and he thought it would be a great step backwards to revert to a fixed tailstock, which was the old style. He thought they were on the right track by having an arrangement to alter the alignment if desired. It was very handy when taper turning. He

did not know of any taper-turning attachment which was so effective, if one was turning long tapers as a set-over poppet or tailstock.

The author referred (page 263) to the introduction of self-opening dies. Self-opening dies were very good. His firm made them, but there were plenty of jobs for which one could not afford to make self-opening dies. Perhaps only a few articles had to be made, and in very many cases more accurate results could be obtained with a solid die. A self-opening die had many moving parts, and anything which had moving parts must be less accurate in working. Automatic machines required two speeds ; at any rate, there must be a speed for turning and drilling, and a much slower speed for screwing. The dies were often ruined if that was not done. The only alteration required was to cross the belt, and in all automatic machines that he had come across he did not know of any machine that was not arranged either with an intermediate gear or an arrangement by which the belts could be crossed. They could either be used open or crossed. As a matter of fact, on an automatic machine it was better sometimes to run with a cross belt, even when screwing was not being done, because then a forming tool could be used on the back portion of the cross slide, and it could be made more rigid than if used with the tool inverted. The practice of his firm was to use a cross belt on their machine for nearly everything. Left-handed tools were used when an article was being made with a right-handed screw, and right-handed tools when making a left-handed screw. The speed for drilling and turning was therefore in one direction, and it could be fast, while the speed for screwing was in the other direction and much slower.

With regard to Mr. Donaldson's remarks (page 318) about camming up an automatic machine double, that was a very general practice on ordinary automatics. It was a very necessary practice, because there were only two automatics, he believed, at the present day in which the holes which were not being used could be skipped— one the Brown and Sharpe and the other the Wolseley. One could locate on either of them to one or more holes. All the other holes were skipped, and the other operations, such as those on the cutting-off slide and others for operating the chuck, were speeded up in

(Mr. Herbert Austin.)

proportion. It was very handy of course to cam up double, but it meant double expense in making the tools. There were also two sets of tools to set to work correctly, whereas it was difficult enough to set one set. The author referred to the spindle (page 264), and said, " It is a point for debate as to whether the spindle should be hard or soft." He did not think it was a point for debate. A spindle could not be too good, considering it was so easy to harden it. In any case, spindles should be ground after they were turned in order to make them a good job. The difference between the cost of a hard and soft spindle was very small; and from his experience he knew that after many years' use of hard spindles they wore out a brass bearing, even a phosphor-bronze bearing, far less than a soft spindle did. It did not matter how good the surface might be in the first place ; it was almost impossible in ordinary practice to keep dirt out of the spindle, as it came in with the oil. The workmen were very careless about the oil covers : they lost them ; dirt got into the oil, and thence into the spindle in very small particles, and wore out the bearings very rapidly. He thought that was even apparent in motor vehicles where the crank-shaft could be case-hardened. If it was sufficiently short to harden, it would be found to last ten times longer than when it was soft.

The author made a remark (page 268) which he thought was of much importance in connection with machine tools, and a point more debated than almost any other regarding machine tools. It was a subject which could very easily have been made one for a whole evening's discussion. He was quite sure the machine-tool trade in general would welcome such a discussion, because there was a great deal of dispute as to whether the American type of raised **V**s or the English flat-top bed was the best. He had used American lathes in manufacturing, and also in general tool making, for something like nine years; although he was not speaking with any ill-feeling towards American tools, for he believed in some cases the Americans made the best machines in the world, at the present moment he would not have another raised **V**-lathe. They were very good as long as they were new, and as long as one wanted to use them for plain turning and not for severe work ; but after a few years they

wore down vertically very badly, and the saddle worked along like
a "crab," and the defect could not be stopped, as there was no
provision for it. It was not right to say that the dirt did not lie on
it, because it did; it lay as badly on the raised V as on the flat one,
and perhaps worse, because it could not get away. It was imprisoned
between the two Vs; the dirt could not be wiped off so easily, and it
did not get pushed away quite so easily. In a raised V the pressure
for the plain turning was down practically vertical, and of course that
pressure must mean that there would be a good deal of wear in that
direction. Everyone knew that wear in a vertical direction did not
affect the diameter of a shaft which was being turned so much as
wear in a horizontal direction. There was no doubt that if an
English lathe-bed were properly made, and had pads fixed to each
side of the saddle, so that it swept the dirt away properly, as was
the case on some good lathes now, it was, in his opinion at any rate,
infinitely better than the raised V, and it would be a great mistake
to alter it. Of course there were great defects in some lathes,
but that need not necessarily have reference to the designs. The
author referred to the adjusting of gib strips (page 266). Fig. 10
showed a style of strip used by his firm wherever possible; but there
was one point with regard to it which he thought had been omitted
—namely, the screw for pulling the strip down on to the bottom
face. The general practice in English lathes was similar to that
shown in Fig. 9. He did not think Fig. 8 ought to be considered.
The first essential in any kind of strip was that it should be bolted
as solid as it could be made with screws to the saddle; and having
done that it should be adjusted afterwards in order to take up the
back-lash or wear. It was no use simply laying a strip in position,
as in the case of Fig. 8, which was not a good pattern. It must be
held rigid, and ought to form practically a portion of the saddle
itself. If that were attended to, and it was adjusted well in the first
instance, there would be infinitely less wear than if the thing were
allowed to waggle about. The general plan of using a taper
adjusting strip was very good, because a bearing was obtained from
one end to the other; but it was loose, and it should be also held to
the slide, and bolted to it hard and fast. He noticed it was said

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(page 268) that if the inside **V** on a raised **V**-bed was lowered, the chief fault in a saddle which was used with a raised **V**-bed was dispensed with ; but, as a matter of fact, that simply increased the centres of the lathe, and the outside **V** on the left-hand side, Figs. 13 and 16 (page 267) must necessarily make the junction between the apron and the saddle weaker, depending upon how much higher it was than the other portion of the bed. The author said (page 268), " Moreover, if the cross slide-way is raised upon the saddle, instead of sunk into it, the slide which fits upon it may be of greater length, thus giving a better distribution of the pressure from the tool when cutting, so adding to the stiffness." The stiffness of the cross slide of the saddle could not be added to unless the distance between the centres and the top of the saddle was decreased. A man might sell a lathe and call it a 10-inch lathe, but if it only cleared about six inches over the saddle it was only a 10-inch lathe when one was turning a job in the chuck, and not when the saddle was underneath it. That was the chief advantage of the English form of bed, because a thinner cross slide could be used, and a much bigger diameter turned than would be possible, unless a very thin top to the saddle was used.

Reference was made (page 272) to the leader screws in some lathes being splined so as to use them for driving the feed mechanism in the apron ; this was not a good system, as it seriously weakened the screw and caused the nut to wear out rapidly. Misplaced economy was the only excuse for such a practice. There was a remark (page 277) which he thought was hardly fair to many English lathe-builders. The usual practice in many leading shops was to place an intermediate gear between the rack pinion and the hand-wheel, and in discussions of this sort credit should be given to those firms who were embodying such essential features.

Exception was taken to the want of elasticity in collet chucks (page 285), pointing out that stock varying much in diameter could not be used ; but there was a simple way of remedying this to a great extent by having steps on the cone which operated the fingers of the pusher-bar. Such an arrangement was often used on an ordinary capstan-lathe, and it was also used on the Wolseley chuck, Fig. 53

(page 282), although the steps could not be seen in the sketch. A statement occurred (page 292) which without explanation would be misleading. It related to the cutting pressure being sustained wholly by the locating pin. A considerable amount of misapprehension existed on this point. On all long or slender jobs the work was supported by a rest, Fig. 78, Plate 38, and as this was a part of the tool-holder in the turret the cutting strains were all self-contained, and no strain was put on the locating pin. Only on short jobs where the rest was not used did the pin take any strain; and as the turret was much larger than that on any other lathe of same size and the pin right to the outside, no difficulty whatever had been found to exist. Owing to the disposition of this turret and the tools in it, work which could not be done on any other similar machine was done quite as readily and very much quicker than on an ordinary screw-cutting lathe.

Preference was given to the horizontal turret with variable travel (page 296), because the wear and tear would be less owing to the movement of turret being only what was required for each tool; but this was only comparative, and as the variable travel machines were much more expensive and difficult to change over from one job to another, one was apt to make use of the same cams for a great variety of jobs, and thus the turret travel became virtually a fixed one, with the additional disadvantage that a proper rate of feed for each tool could only be obtained by making new cams. On the fixed travel machine, on the contrary, a proper rate of feed could be instantly obtained without any additional pieces. In reference to driving the spindle backwards (page 303), this was of course effected by crossing one or other of the belts.

Mr. E. J. CHAMBERS considered that the subject of the Paper was very much too broad. He wished the author had persuaded himself to leave lathes alone, and speak only of automatic machines, which was quite enough for one evening. He could not allow the one or two points the author had brought forward in reference to lathes to pass unchallenged, especially the point of the V versus the flat bed. One speaker had spoken very strongly on that point, and,

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he thought, none too strongly. Forty years ago he was working a wood lathe with V beds, and then he was promoted to a metal-turning lathe with V beds, which at that time was considered the right kind of bed to use. They had their advantages. Before, one could deal with the middle in the way that was possible now. It was not possible at that time, or in very few shops at least, to deal with big flat surfaces for lathes, and to get the best results by machining. He could remember spending many days scraping and filing beds which nowadays there was no difficulty in truing up very readily. The flat bed, to his mind, had immense advantages over the V ; and when he was told by the author that gravity helped the adjustment by bearing down on to the V, he thought that gravity was very kind in going down that way. But if it went down that way it could go up again, and therefore there must be some play which ought not to be in a lathe if gravity were going to do the work which the author suggested it might do. With the V underneath properly adjusted, there was no such thing as a lift of the saddle ; it was made so that it was a perfect fit, and lubricated with the finest film of oil. Certainly the lubrication of the flat surface was very much easier than lubricating a V. Those who had had occasion to use Vs for other things than lathes would have found there was a very great difficulty in lubricating the top part of the V. The bottom part got plenty of lubrication. For automatic machines a bath of oil was about the best thing for it to work in. It was an essential in that case, because it was producing an enormous amount of work at the most rapid speed possible. The remarks in the Paper, to his mind, mainly applied to automatic machines, certainly not entirely to lathes. With regard to spindles, he was entirely in favour of parallel spindles with conical adjustment.

On the question of turning taper, for the information of the members he might say that a few years ago he had wanted to turn taper, and at the same time be able momentarily to leave off turning taper, and go on turning parallel. He had not found the slightest difficulty in doing that. He went to one of the leading tool-makers, and told him what he wanted and how he proposed to get over the

difficulty. The tool-maker had no difficulty whatever in arranging for him a guide bar which, placed at the back of the lathe bed, was in its normal condition parallel with it. To that bar he connected the end of the transverse slide, and then at any time that he wanted to work taper he simply shifted the bar to the taper required by means of a nut at each end of the slide—one to release and the other to tighten. He would turn taper for a certain distance, and, by releasing one nut and tightening the other, could immediately turn parallel ; he had no difficulty whatever in carrying that out. With regard to working perfectly true, all the work had to fit a gauge, which was a simple matter. As regards screwing, a good deal had been said as to withdrawing the dies. His experience was that instant release of dies could be obtained with absolute accuracy of screwing ; those engineers who said it could not be obtained either were interested in selling something else, or they did not know what could be done. Any engineer who chose to work at it could make dies which would screw to the greatest accuracy, and also at the same time have an instantaneous release.

The question of screw-making machines he dared not enter on that evening. He admired the ingenuity of their brethren across the water. He had bought some of their lathes, and was using them. The reason he bought them was because he could not at the time get delivery of any English lathe worth having under six or seven months—he was speaking of about two years ago. When six or seven leading tool-makers in England informed him that they could not promise delivery of a lathe under six or seven months, he thought it was about time to find out what the Americans were doing. He must say, however, that he had experienced some difficulty with the American lathes with V beds when he wanted to put a heavy cut on them ; they objected to do that sort of work. He was shown over a large works some years ago almost entirely fitted up with American machinery, and the engineer boasted to him that there was not a single machine in the shop which had a foundation ; they were all " self-contained," and were simply screwed down on to the wooden floor. Replying, he said that if those machines were put on to

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cuts which he was doing every hour of the day and every day of
the week, the machines would "dither" out of the shop. [*See also
page* 359.]

Discussion on 22nd *February* 1901.

Mr. W. W. MARRINER said that, by the courtesy of Mr. Yarrow,
he was able to give the members the results of his firm's experience
with several types of lathes mentioned by the author.   Some years
ago Mr. Yarrow went to America, and was so struck with the special
advantages of their lathes that he brought several back with him,
putting them to work at Poplar, where they had proved most
successful.   His work was very varied, repetition jobs not being
numerous, as on torpedo boats standardised fittings had to be
sacrificed to convenience and questions of weight.   Dealing first
of all with the ordinary lathe, his firm possessed several very good
examples, such as the Berry, Muir, Lang, and Hendey Norton.
The Lang lathe had a special form of bed, and as this did not appear
in the Paper, he had had an illustration made, Fig. 113 (page 327),
showing the bed and saddle of the machine possessed by his firm.
The saddle rested on surfaces A and B, while it was guided along
the bed by the square faces C and D only.   A space was left at G to
ensure that there was no bearing.   The plates, H and I, prevented
any lift taking place while cutting.   When slack, the adjustment
was made by moving on end a taper wedge.   The advantages claimed
for this bed were first of all that the guides for the saddle were not
very wide apart, and the cross corner twisting was avoided, such
as would be obtained if the guides were much greater distances
apart.   The members would understand what he meant if they
thought of trying to pull out a drawer with only one of the two
handles.   Another advantage claimed for this bed was that it was
capable of very good adjustment, and had good broad wearing
surfaces.   This lathe also had the triple gear illustrated by the

Fig. 113.
New Form of Bed (Lang).

author, Fig. 29, Plate 23. The Hendey-Norton lathe had the multiple-feed change-gear, which was also illustrated, Fig. 31, and it was a first-class tool. It excelled when working at small pistons and connecting-rods; and for that class of work it was a difficult lathe to beat. If he went on to consider English versus American lathes, and went into a little more detail, the members would find that he supported the author in most of the statements he had made. The advantages of an English lathe over

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an American lathe were:—(1) that a very much heavier cut could be taken with it, but in the majority of instances the depth of cut was limited only by the strength of the job in the lathe. and not by the lathe itself; (2) that the depreciation was less, because as a rule it was of a much heavier make. But depreciation was only a very small item of the working expenses and the wages account in working a lathe. Turning to the American lathe, the advantages were:— (1) the multiple-feed change-gear, which could be very easily put in without stopping the lathe; (2) the feed guide could be reversed without stopping the lathe; (3) the handles for the slides were most conveniently placed, and so geared up that a very fine adjustment could be made; (4) all the handles for putting in the self-acting feed-motions were in a handy place, so that the operator had not to reach to the end of the lathe, or to reach over the lathe, as in some English types; (5) the back gearing was, almost without exception, machine cut, and of a finer pitch than was usual in this country, which made the lathe run smoother; (6) the bed was made in the form of a cupboard under the fixed headstock, which was a nice place in which to keep the tools. He wished to emphasize the point of convenience by relating an incident that happened in his experience. He was going round the works of one of the best English tool-makers, and was taken to see a machine expressly designed for finishing off the ends of screws. It was a first-class machine, and finished off the end of a screw in about seven seconds; but it took the man two minutes to put another screw into that machine, because the chuck was not adjustable, and because the workman did not happen to have a properly fitting spanner. That impressed on his mind the great importance of reducing the time of getting the tool to work, or changing the tool, quite as much as of reduction in the actual time of cutting. In other words, convenience was a great factor in economy. The Americans were the first to recognise that. He thought a good deal of credit was due to the people who first introduced American machinery into this country, amongst whom he would like to mention Messrs. Churchill.

Passing on to the turret lathes, his firm possessed a Jones and Lamson machine, which was really a first-class tool. It excelled in

work such as long bolts, special studs, valve spindles, etc. Several jobs could be done in the Jones and Lamson lathe, which on an ordinary lathe would have to be put in charge of a very highly skilled mechanic. He did not think any engineer's shop was complete without a Jones and Lamson lathe. Turning to the full automatic lathes, his firm possessed a large size Herbert capable of turning 1-inch steel bolts, and a small size Pratt and Whitney capable of turning $\frac{1}{2}$-inch brass bolts, and he did not think that they could want better tools for standard bolts. The lathes were run at a constant speed, because it was found that the loss in so doing was more than balanced by the simplicity of the overhead gear, and by the durability of the cutting tools. If any of these lathes were to be made a success, a great deal of attention must be given to them when they were first installed, as it was not fair to expect any of those tools to do exactly what was wanted in the best way unless alterations were made to suit the quality of the material, the quality of tool steel usually kept in stock, and even to make some to suit the attendant. Another point was, that there must be a really first-class tool room, as the tendency of all specialised machines was to take the responsibility off the operator and to put it on the foreman and his staff of tool makers. He would like to see one fitting more generally put on lathes, namely a thoroughly good form of back-stay moving with the saddle, so that a job was supported directly behind the tool. It was a somewhat difficult thing to design so that it did not get into the way, and it must also be so designed that it would suit every diameter, and that a piece of wood had not to be made to suit every diameter that required to be turned. He had only seen one which came anywhere near to what was wanted, and that was made by Messrs. Ludwig Loewe, of Berlin.

Before concluding, he desired to offer a warning to gentlemen about to buy American lathes. Really first-class tools were made in America by some makers, but by others some very bad ones were turned out. As in England, the good makers lost their reputation abroad because their rivals were more pushing with an inferior article, and therefore if one was buying an American tool it was necessary to be quite sure of the maker. He had mentioned the

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Paper to Mr. Yarrow, who had said that he would be very delighted
to show anyone the American and other special tools at work at
Poplar, if they would make an application in writing. He,
personally, would only be too pleased to show the author over the
works if he would honour the firm with a visit. In conclusion, he
heartily congratulated the author on the splendid Paper he had read
on a subject which was most difficult to put into the form of a paper.

Mr. P. V. VERNON, before dealing with the question of the
details of the machines, wished to add his tribute to the compliments
which had been paid to the author. The Paper must have entailed
an enormous amount of labour ; and anybody who appreciated the
difficulties of assaying the merits of various makes of machine tools
would agree that the author had carried out his task in a most
impartial manner.

There was one remark made by the last speaker to which he
ventured to take exception. Mr. Marriner mentioned the name of
one particular make of lathe, the Jones and Lamson, and stated that
in his opinion no shop was complete without it. He maintained
that that was not a fair statement to make, because it assumed that
the Jones and Lamson lathe would do what no other lathe would do,
and was superior to all other machines. That was hardly fair to other
makers who perhaps had equal claims to merit on behalf of their
machines. With respect to the details of the mechanism described,
the author said (page 261): "(e) When screw-cutting or chasing
from the leader-screw, a single movement should suffice to release
one screw and withdraw the tool from the work." That was a good
thing, but as stated in the paragraph, it was not complete. Together
with the movement which released the nut and withdrew the tool,
should be some mechanism which would enable any pitch to be
engaged instantly. Any practical mechanic would know the
difficulty with an ordinary lathe. When cutting odd threads, the
operator had to keep one eye on the spindle gear and one eye on the
guide screw, and he generally had to watch for chalk marks to come
round simultaneously. On an ordinary lathe with an ordinary
screw-cutting odd pitches, it would still be a difficult, and to some

·extent a long operation, even with the quick withdraw motion.   He
thought it was necessary to include in the clause an arrangement of
leaders or similar mechanism, by means of which any thread could
·be cut without any danger of cross-threading, and without the
workman having to watch for the position of engagement.

In the Paper there were three methods of taper turning described :
·first of all by setting over the centres, secondly by compounding the
longitudinal and cross-feeds, and thirdly by means of a taper former
bar.   In the discussion another method had been mentioned by
Mr. Wicksteed, namely, taper-turning by compound rest.   Each of
those methods, except the taper bar, had several important
·disadvantages.   Taking the method of taper turning by compound
rest, the disadvantages of that were, first of all, that only short
tapers could be turned, and secondly that the feed was not self-
·acting.   The next method, by setting over the centres, had the
serious disadvantage that the centres of the lathe did not bear
properly in the centre holes in the work, and consequently the centre
holes in the work wore badly, and the work produced was not true.
`The third method, compounding the cross and longitudinal feeds,
had the serious disadvantage that only certain tapers could be
·obtained, that is to say, only such tapers as the change wheels
supplied with the lathe happened to give.   In taper turning, in
gauge making, or in doing any taper work in which taper male parts
required to fit into taper holes, it was necessary to make fine
adjustments of the taper.   For instance, suppose one were turning
Morse tapers in a lathe, the correct taper could never be obtained by
·compounding two feeds.   These tapers were not uniform.   No doubt
originally they were intended to be, and approximately they might
be said to be a 1 in 20 taper, but only two of those tapers agreed.
The others differed in a small amount.   With a compound rest it
·could be obtained by slightly altering the angle of the rest, but
that method had the disadvantage he mentioned.   It appeared to
him that the only method of taper turning on an ordinary
lathe which was satisfactory was the taper bar.   The self-acting
feed could be used, the taper turning arrangement could be used
in conjunction with a quick withdrawal when taper turning or

(Mr. P. V. Vernon.)

chasing. A taper of the whole length of the lathe could be produced, and generally speaking the setting was more easy to attain, and minute adjustments were possible. Another method of taper turning, which was not mentioned, was the Grant taper-turning lathe, which, for the work for which it was intended, was an extremely good tool. The fast and loose headstock were set over bodily to the taper quite independent of the bed, but of course the lathe was hardly suitable for miscellaneous work, but simply for tapers.

With regard to paragraph (j, page 262), also Figs. 57 and 58 (page 286), and Fig. 63, Plate 30, they illustrated various methods of feeding forward the bar automatically in the lathe. The figures illustrated what were known as roller feeds, and he would like to point out that those roller feeds had not all the advantages which were sometimes claimed for them. In the first place he was prepared to state from practical experience that a roller feed to the bar in actual practice did not save time. On a capstan lathe an operator, when he wished to feed forward the bar, released the chuck with one hand, and at the same time placed his other hand on the bar which was fed forward to the extent necessary, practically as soon as the chuck was released. He was prepared in competition, on a turret lathe, to feed forward the bar to any required length in less time than one of the advocates of the roller feed would feed the bar forward with his lathe. Another reason why the roller feeds illustrated were not so efficient as was claimed was, that they would not work when the lathe was stopped. Most people who had experience of turret lathes, especially working on heavy work, would know that the back steady, which usually consisted of four screws at the back end of the spindle, was used to support the bar, and that when heavy forming was being done the back steady was tightened upon the bar : consequently the operator had to stop his lathe in order to release the back steady, and start his lathe again in order to feed the bar forward, and then stop it again in order to tighten the back steady before starting the machine for its work, which of course was much longer than feeding the bar forward by hand. Another objection to the roller feed was, that a great deal of time was lost

with it when using bars which were irregular or not parallel, as the
feed had to be adjusted to suit the variations in the bar.   Another
very strong objection to the roller feed was that it was at the wrong
end of the spindle.   On most of the turret lathes described, which
had roller feeds, the spindles were about 3 feet long.   Users of
capstan lathes did not generally use bars more than 7 feet long, so
that when the bar had once got inside the roller feed, the efficiency of
the roller feed was very much reduced, as the only way in which it
could be used was by putting another bar in to push up the first bar,
which was not found to be a very satisfactory method.   The ideal
place for having an automatic feed was just inside the chuck.

The author stated in paragraph (k, page 262), as one of the chief
requirements of a turret lathe, that the turret should revolve and
locate itself automatically.   That, in his opinion, was an extremely
good thing on small lathes ; but on large lathes, particularly of the
Jones and Lamson type, the Ward turret lathe, or the Herbert
hexagon-turret lathe, automatic revolving was, to his mind, a positive
disadvantage, the reason being that it was advisable as often as not
to revolve the turret backwards.   Taking a long job having several
shoulders, after the shoulders were turned with the turning tool, they
required squaring down.   They were usually squared down with
a narrow tool in the cutting-off slide, and the tool required to
be brought into operation two, three, four, or more times during
the production of one piece.   Consequently automatic revolving
necessitated that the turret should be turned completely round each
time this tool needed to be used, whereas on a turret which had not
automatic revolving, the tool could be turned out of the way to the
next place, and then brought back.   Another objection to the
automatic revolving turret was that the saddle carrying it required to
be taken back to the same position each time to revolve the turret,
whereas when the turret did not revolve automatically, it could be
turned at any part of the bed by hand.

The author stated (page 263) that " the introduction of self-opening
dies has rendered it unnecessary to provide any reversing mechanism."
Of course when one was tapping, reversing mechanism was necessary,
and as a matter of fact all automatic machines had it.   Fig. 5

(Mr. P. V. Vernon.)

(page 265) showed a spindle provided with a ball bearing. He might mention that experience had shown that such bearings were of no use for accurate work, as, in order to get satisfactory running, a certain space was required between the balls, and that space was liable to come all on one side of the bearing at one end of the spindle, and all on the other side at the other end, producing a kind of wobbling, gyrating motion. Ball end-thrusts, however, had been used with great success where the pressure was not too great.

Archdale's change feed-motion was illustrated in Fig. 30, Plate 23. He quite agreed with Mr. Wicksteed's criticism that that would have been much better arranged if the various feeds had been obtainable progressively. They could be obtained, a well-known instance of it existing in the Panhard gear as applied to motor cars. An objection to that form of feed was that the change could not be made while the lathe was running. With reference to the question of feeds generally, and of what he might call the craze at the present time for a large number of feeds, he would point out that a large number of feeds in many cases was not altogether an advantage. In the shop with which he was connected, it was the practice to turn some of the steps off the cone pulleys of the American lathes, in order to reduce the number of feeds, because it was found that the tendency of the workman was to run upon a slower feed than the work could be done at. He thought it was advisable to qualify the advantages of large numbers of feeds by that particular tendency on the part of the workman.

Dealing with the question of English and American types of apron (page 277), time would not permit him to say very much. The chief defects which he had noticed in American aprons, and the chief complaints made against them, had not been unhandiness in any case, but always weakness. The general complaint against the English type of apron was seldom weakness, but unhandiness. If the American apron were designed from the point of view of the English tool-maker with regard to strength, he thought there would be very few complaints about it. The bottom paragraph on page 277, the top paragraph on page 278, and also Figs. 39 and 40, Plate 27 ; and Fig. 43, Plate 28, illustrated and described

American aprons in which the feed was driven by a splined screw. The chief objection to that method of driving the feed appeared to be that the feed was always a certain function of the screw pitch to which the guide screw was set. On quick work a man would not have time to go to the end of his lathe to shift the change-gear, even if it was a change-gear of the Hendey-Norton type. On exceedingly rapid work it was very necessary that the feed rate in the apron should be just right, and that the screw-cutting gear should also be just right to cut the screw, and that the change should be made by the workman instantaneously, without having to move to the end of the lathe. On quick work it might mean as much as 25 per cent. of the time required to do jobs.

He hoped the author would not mind his making criticisms, but a remark made by him as to the use of leaders seemed to his mind to convey that the main object of a leader was to save wear upon the screws. That was not so. The main object of a leader was to save time, and not wear, and time was saved in the manner he had just explained for engaging the nut without any danger of cross-threading. The author said (page 295), "As a rule two speeds only are introduced, one suitable for turning the larger sizes, and the other for screwing with a die. It is thus evident that, if the machine is put upon brass of a size smaller than its maximum, the economy is doubtful." That was not quite a correct statement. Every automatic with which he was acquainted had a larger range of speeds than that. And most automatics had a range of at least six speeds. On the same page various types of turrets were discussed. On the mitrailleuse turret there was one very serious disadvantage, namely, that there was very little room for tools. On jobs of a complicated nature, that was, on jobs in which automatics showed the greatest economy, the tools could not be got in. Referring to Figs. 89, 90, and 91, Plate 43, he might perhaps add a little to the descriptive matter given in those diagrams as to the operations which could be performed on that type of automatic. The diagram gave the first operation for the turret as starting, that meant coning the end of a bar. The same cam could be used for centering with the same feed, or for a stiff starting drill to get a true centre for starting a drill, or facing, or all or any of those

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operations. The next operation on the diagram was rough turning.
The cam for that operation was also used for drilling or both at the
same time. The third operation was finish turning. That of course
could also be used for reaming, or the box tool could carry a reamer,
allowing the finish turning and reaming to be done simultaneously.
Then came forming from the cross slide, a steady bush fitting a male
part, or a steady peg to fit the female portion being used, and of course
the shape of the form tool could vary according to the work required
to be done. The screwing cam, of course, could be arranged for
tapping, and then cutting off. He simply made those remarks in
order to show how universal the machine was, and how those
operations would cover practically any job required to be made
from a bar.

In conclusion, a discussion of that kind was he thought of very
great service to a designer. As a practical designer it helped him
to realize the point of view of the people who had to use the machine ;
and he also had forced upon him the points of view of people who
were designing competing machines. He felt, from the point of
view of the machine-tool maker, that the discussion would be of
value : he hoped it would be of equal value from the point of view
of the users.

Mr. VERNON subsequently sent two photographs showing the
arrangement of the tools for producing breech blocks upon a
hexagon-turret lathe. Fig. 114, Plate 52, showed the lathe with a
complete equipment of tools for producing breech screws for
12-pounder, 4·7-inch, and 6-inch quick-firing guns. Fig. 115 was a
plan of the turret with tools for boring and reaming 6-inch breech
screws. The bell chuck was in halves, and was shown with the
top lifted off. One of the holders was arranged for taking a number
of interchangeable tools which were shown in such a position as to
make the operations quite clear.

Mr. G. H. BANISTER thought the Institution was much indebted
to the author for the Paper. It would constitute a valuable work of
reference for those who were interested in the performance of that

class of machinery, as in a concise form it dealt with the different kinds of machines now on the market.

While not desiring to endorse what Mr. Marriner said so far as specialising on one form was concerned, he wished to bear tribute to the excellence of the Jones and Lamson lathe. In his own experience it was capable of doing excellent work. In association with this lathe he would like to refer to the remarks made in the Paper on the sectional beds, that is, the question of flat beds or V beds. The author stated that in the case of the V beds gravity played some part in steadying the rest; and without desiring to attach too much importance to the value of gravity in the matter, he suggested that something of the kind did occur, that the Vs were placed directly under the tool, and that the saddle placed on Vs tended to steady itself by the downward pressure of the tool and the weight of the saddle. Altogether a very steady rest was obtained, and it worked without being nipped hard down, as was necessarily the case with the flat bed. It was desirable therefore to adopt that form for light machines, but for machines which had to take very heavy cuts he should be inclined to go in for the English form. He did not know that he ought to call it the English form, for unquestionably the V form was originally an English form too. With regard to the limitations of the full automatic machine, he was inclined to think that when the largest diameter of the work to be done ran about 2½ inches, it was closely approaching that at which it would pay to do work. Taking for example a pointed projectile about 2½ inches diameter, it would be seen that there was very little waste material. The article was almost cylindrical throughout its length, and yet in that particular job it was quite a question whether it paid to do it on the automatic machine, taking into account the first cost of the machine. In fairness, however, he ought to point out that the material used on that job was of very high grade, and played up rather with the tools. On the other hand, if a milled screw-head 2½ inches diameter, ⅜ inch thick, and a half-inch diameter screwed body 4 inches long, were taken, it represented the worst kind of job which could be done on an automatic machine. It had one very short portion of large diameter, and a long part of small diameter. Clearly a great

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deal of stuff must go to waste, and if it happened to be made of bronze instead of steel he very much questioned whether it would pay. Under circumstances like those, it seemed almost a pity—although he confessed the author must have given a great deal of time to the preparation of the Paper—that it did not contain any reference to the magazine machine. He was inclined to think the development of the full automatic machine of large size would be in the direction of using the magazine hopper feed, so that there was as little waste material as possible while carrying out the work.

The author referred (page 262) to the self-centring chuck. The reference was, he thought, in connection with the capstan lathes, where of course it was quite correct that the chuck should have a wide range of grip; and to some extent this was true also for full automatics. He would point out however that it was very questionable whether it paid to turn roughly wrought bar in a full automatic. It probably paid better to use drawn rod, and therefore the wide range of grip was not so necessary. In connection with the drawn rod, in passing he would like to refer to an experience of his own quite recently. The material, as its name implied, was drawn, and in drawing it the tensile strength was put up, and the percentage of elongation was decreased. He was sure from recent experience that there was considerable risk in using that material, as some might be obtained which would not stand vibration. If it was used for bolts, a risk was run of having the bolt-heads jar off, especially when they were used on structures such as gun-mountings, subject to vibration. He thought it was desirable that drawn bar should be tested, to make certain that it had been properly annealed.

It was stated (page 276) that the tool of the lathe should be adjustable in a vertical direction, and an illustration was given, Fig. 50 (page 281) of a tool-holder of a lathe by Messrs. Humpage, Jacques, and Pedersen, of Bristol. It would be noticed that in the socket for the tool the set screws were jamming on the side of the tool. Without stating more than a member of the firm told him, he would like to point out that the firm claimed that this formed an arrangement for vertical adjustment. They claimed that, without the use of packing, it was possible to set the tool to a level in the

rest, lifting it from the bottom of the block, if necessary, and jamming it to the side.

One difficulty which had been experienced in the Ordnance Factory at Woolwich, in regard to the adoption of American machinery, was that many parts of American machines were supplied with cast-iron bearings. The loose pulleys, for example, were supplied of cast-iron, and were not bronze bushed. He had no reason to doubt that in time those pulleys would run correctly, but it had been almost their invariable experience that when started they were rapidly seized, and gave no end of trouble. The American lathe representatives, who had been spoken to about the matter, claimed that if the pulley was properly oiled and lubricated and allowed to run, in a short time it obtained a close glazed surface, and would run for years. But as a matter of fact it was exceedingly awkward, to say the least of it, to have the bushes fire, or the pulleys fire, as soon as the machine was started. He should advise, on the whole, that it was better to have the pulleys bushed with bronze at starting. Another disadvantage was that one ran a risk, with cast-iron pulleys without bushes, that the bosses might be so thin that when they did wear there was no possibility of repairing by bushing. In conclusion, he wished to call attention to a pipe-axle-box for an artillery wheel (page 357). He thought it formed an excellent illustration of the economy that resulted from the use of lathes of the turret type—the inclined-turret lathe in combination with special tools. That particular job was done on a No. 6 inclined-turret lathe of Messrs. Herbert, Fig. 114, Plate 52. The pipe-axle-box alone was made up of three things, two flanges, and a central pipe. The pipe alone was produced in about thirty-two minutes, whereas it originally took, and still took under the ordinary method of work, about three hours. [See also page 356.]

Mr. WALTER DEAKIN said it was remarked by a gentleman who spoke at the last meeting, that the Paper bristled with points for discussion; and the fear one was naturally embarrassed with in attempting to say anything about it was, that one might trespass too much, and preclude any other individual from having a fair

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opportunity of taking part in the discussion. They all agreed that
the author had discharged his task very creditably, though it was a
somewhat difficult one, everyone must admit, in selecting the
different makes of lathes, especially modern ones, and endeavouring
to bring facts before the Institution, without giving undue
prominence to any particular maker.

In taking part in the discussion he wished to say a word on
behalf of the older form of English lathe, which seemed to have had
a great many enemies and not many friends. In the first place, the
tool rest of an ordinary English lathe with four studs and two clamp
plates possessed a very great advantage over an American one in
respect to the rigidity with which the tool could be held; and also its
convenience for a great many operations, such as screw-cutting and
cutting up to a shoulder on a shaft, it was very much better to have a
rest which would enable one to put the tool close alongside the outer
edge of it, instead of having the tool across at an angle which in
screw-cutting was a disadvantage painfully obvious to all those who
had the privilege of using a lathe. A great deal had been said about
the impotence and uselessness of the slide-rest, but practice
demonstrated its utility. One had to look at the English lathe in
view of the service it was intended to fulfil, and he thought that
those who looked carefully at it could not help saying that those who
designed it knew something about what they were doing—they could
see that it had many points in its favour. It was not fair to look at
the English sliding, surfacing and screw-cutting lathe as being a
special tool. It came into existence when it was required to do
efficiently everything that came in its way. That would be a big
order to put before any special tool. The slide-rest, as had been
before observed, was very useful for certain kinds of tapers; for
instance, in turning an obtuse angle one could swing the slide-rest
round, and do the job in less time than would be required to attach
and adjust many of the tapering arrangements referred to. Practical
turners would be familiar with the many instances in which it was
necessary to have slight adjustments which were obtained with the
slide-rest, but were not possible with the ordinary American type
saddle without compound-rest. In cutting a coarse thread screw, a

V thread about 4 or even 2 threads per inch, it was a matter of impossibility to get a good surface on that thread by pushing the tool into it, and expecting it to take the whole surface of the cut; and it was necessary in such work to adjust the tool on one side, and then on the other side of the thread. Then again, the slide rest was a great convenience when adjusting the tool after regrinding. The geared-down arrangement of the American saddle had been referred to as being preferable to the simple shaft and a rack pinion of the English lathe. There were practical advantages in favour of the latter, especially in long work, where it was necessary to travel the saddle quickly from one end of the lathe bed to the other, as in shaft turning or screw cutting. In such cases as these the direct gear was a decided gain. He remembered a lathe used for cutting leader screws, about 7 to 9 feet long. For the supposed convenience of the man, and following American practice, a geared-down arrangement was put on to the saddle of this lathe; but the man very quickly asked for it to be removed, so that he could get the work out quicker, and thus earn more money. Those matters must be considered from a matter-of-fact point of view. He could assure those members who had had little experience themselves that, if coarse thread screws had to be cut of any length with a geared-down saddle, they would be thankful to get back to Whitworth's old arrangement, and march up quickly to the end of the screw, instead of wasting the time in getting back with a geared-down arrangement. Those were some of the points of advantage in the English lathe. There were others also, which showed that those who designed the English lathe knew what they were doing. They put some features into it, at any rate, which were very advantageous from the point of view of the rapid production of work.

Coming to another question in regard to the English lathe, he supposed English mechanics were thoroughly familiar with the position of the screw in the Whitworth lathe. He did not know whether anyone had the audacity to say that that screw was not in the right place. If they looked at some of its competitors in this and other countries, the latter would be seen to have departed from

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what was correct.   That was a point in regard to the ordinary
lathe which was worthy of consideration, and which a great many
designers had departed from, much to the detriment of the tools
they produced and of their reputation as designers.

With regard to the vexed question of beds, he was not going to
decide which was the best bed :.that had to be decided to some extent
upon the purposes for which the lathe was constructed.   He thought
something, however, might be said in favour of Vs.   It appeared to
him, from observations he had made, that the chief disadvantage
in connection with most V beds was, that the surface area was
insufficient, and in a great many the material they were made of was
not good enough.   He thought, given sufficient surface area for
many lathes, a V bed would be preferable to a flat top bed.
With regard to some of the points raised that evening in connection
with the construction of the flat-turret lathes in use at the present
time, there were a great many differences of opinion as to the
utility of various parts, and that difference of opinion existed quite
as much among the users as among the makers.

With regard to whether it was easier to revolve a turret
automatically or by hand, he was in favour of revolving the turret
automatically.   Anyone who was theorising on the matter might
think it very much simpler to move it by hand without the running
back, such as in the Jones and Lamson and some other makes of
lathe : but imagine oneself in the position of the operator, having to
revolve the turret by hand some hundreds of times a day to produce
articles with the rapidity with which it was asserted they could be
turned out ; it seemed to follow that the man would be very tired
if he had to release the lock bolt and pull round every time he
changed his tool, instead of being able to accomplish all these
movements by the return stroke of the saddle and the automatic
revolve.   Something at least was to be said on the ground of the
advantage of the automatic revolve.   There were some advantages
as well as disadvantages about roller feeds, and if he were of a
competitive nature he might make a challenge to move a bar quicker
with roller feed than it could be done by stopping the lathe and
working it by hand, unfastening the chuck, pulling the bar through,

and starting the lathe again.   Under some circumstances which might be arranged, he would have a good chance of success in the competition.   One point about all these lathes was, that the modern types of lathes to which much attention had been drawn, were in many respects great labour-saving machines; and no doubt they would find their way through in getting at the best combinations by continual effort and discussion amongst those who used them. Before sitting down he wished to make one observation with regard to English *versus* American tools, which he thought accounted in some measure, he would not say altogether, for the position of the English tool trade today as compared with the American.   A few years ago if an English tool-maker had ventured to suggest to an engineer that it was possible for him to do his work better than he had been doing it, he would have been told that the user knew more about his business than the tool-maker did.   By a process of education, for which the American had been to a very large extent responsible, many engineers had condescended to consult the tool-maker as to methods of producing work, and that had induced tool-makers willingly to give more attention to these matters.   They all knew very well that there had been a great idea of secrecy among manufacturers some years ago.   When a man came to a tool-maker for a lathe, say an 8-inch or a 10-inch lathe, he did not disclose the purpose for which he required it, but just took it as it was and tried to work out his own salvation with it.   The American had come and had shown him that he could get his salvation worked out a bit easier if he would allow his tool-maker to be, to some extent, his consulting engineer.   He believed English engineers would support English tool firms who showed the like enterprise.   While some had said that American tools were indispensable to a proper tool-shop equipment, it was to be hoped that tools of English manufacture of an equally efficient nature would be found by the intelligent engineers of England to be absolutely necessary for their shop equipment.   A discussion such as they had had was calculated to increase very largely the intelligent interest in tools, and ought to be an advantage to everyone, whether a maker or a user.

Mr. WILLIAM SCHÖNHEYDER said he was sorry to say he had not a very large experience of automatic tools, but he fully recognised their ingenuity and great use. Some little while ago he required a tool for forming a great many rods of a very peculiar shape. He searched several makers' catalogues and various tool shops, and the machine he liked the best and which he felt would do the work was called the Swedish lathe, mentioned in the Paper (page 291). He asked the author if he would be kind enough to give that tool a proper place, by either mentioning the maker's or the inventor's name. In that lathe there was an arrangement similar to one which he had himself thought out and designed some time ago, by means of which it would readily turn a piece of material to almost any shape required, with a very simple adjustment, and without making very expensive tools. On the back of the lathe bed was fixed down a flat template, of the shape the material was required to be turned down to. The slide-rest could be moved backwards and forwards and in and out, by two very convenient levers. On the back of that slide-rest which held the tool was a kind of pointed guide, made to travel along the flat template fixed to the bed. There was, of course, a tool fixed in the rest which had the same shape as the end of the pointer, say a half-circle-ended pointer, and a circular tool. By guiding that pointer so as to touch the template fixed at the back of the lathe bed, the tool was made to turn exactly in the manner required for producing the work. A tool of that description he should make out of round steel for preference, and grind to a slope at the top. The advantage of that was, that it could be readily ground, and never lost its shape. It appeared to him that there were two classes of machines for doing that work in the lathe, the class that had guides as described, and the other class which had special tools ground to produce special work, which to his mind was far the more expensive one. No doubt the two methods of doing the work were merged into each other, and could not always be used indiscriminately. There was another small matter he would like to mention as a lesson to young engineers. Some parts of the machines, if he might be excused for saying so, exhibited some bad designing. There were some small

screws, about $\frac{3}{16}$ inch diameter or something like that, for adjusting tools up to their proper position, and, instead of having a proper head on them for turning, there was simply a notch cut in the end of the screw. There was no place for a good spanner; a screw-driver would have to be used, always an unsatisfactory tool for such a purpose. The screw-driver very soon wore out the notch: it had already done so in one of the machines exhibited, and it was impossible to put a fine adjustment on to the screw. If a screw were made for that purpose it should be of larger diameter: and it should have a proper square head upon it, so that a spanner could be applied as a long lever. A nice adjustment could then be given to it, in setting the tool forward so as to produce work of the exact dimension required.

Mr. T. S. Bentley said he wished to direct his remarks more especially to the various forms of lathe bed. That the two principal types, which might be called English and American respectively, had each considerable advantages was proved by their universal adoption on the two sides of the Atlantic. Mere destructive criticism led nowhere, and it was only by looking at the particular objects aimed at by the designers that the Members could appreciate their productions properly. Granting that engineering design was a matter of compromise in all cases, the result depended entirely upon the relative importance given to the various considerations involved. That was just where the American and English designers differed, and it accounted for the divergence of practice between them. A cutting tool would remove a certain maximum amount of material in a given time, and broadly speaking it would do in either of two ways: either taking a heavy chip at a moderate speed, or with a quick speed and a lighter cut. In certain cases one or other of the methods had a special advantage, but, generally speaking, the rule held that either practice could be adopted. The tendency in the English shops was rather towards the heavy feed and cut and a moderate speed, while the American practice was towards high spindle-speeds and proportionately lighter cuts; and that explained the different attitude with regard to design. Looking at the English

(Mr. T. S. Bentley.)

type of bed, with the broad flat top and V guide, its chief point was strength and rigidity, which of course was necessary to stand up against the heavy cuts of which he had spoken. Along with that design, and uniform with it, there was usually a solid spindle, coarse and broad gearing, and compound-rest with the double tool clamp— the most rigid tool-holder known. In the American lathe other objects were aimed at, especially speed and easy handling. The raised Vs gave a lighter running carriage, the spindle was generally hollow, and consequently lighter running, the gearing invariably cut, and usually proportioned throughout, so as to favour high spindle-speeds. The typical American tool-post was easily and quickly adjusted. Though lacking the extreme rigidity of the English type, it was equal to the lighter cuts aimed at, while also securing in high degree that most important feature—handiness.

Referring to durability, which was one of the points upon which special stress was laid, it seemed to him that the question depended entirely on what was understood by the term. There were plenty of English lathes that had been running perhaps twenty or thirty or more years, and were still doing hard service. It usually happened that those lathes needed to be humoured by the particular men who worked them, and who understood their little ways. As the guide screw was frequently some distance in front of the bed, there was a cross-bind of the saddle which was increased by the wedging action of the grinding Vs, and caused them to take practically all the wear. The resulting error was in line with the tool, and was consequently doubled on the diameter of the piece being turned. On work of any length, it frequently became necessary to follow the cuts carefully with the calipers, and ease the tool in or out to produce an approximately parallel job. Such a result was neither cheap nor satisfactory, and the value of such durability was more than doubtful. In his opinion the term should refer to the length of time a machine would retain reasonable accuracy, and continue to produce to advantage. In the American type of lathe, the raised Vs favoured the keeping of alignment, and that was a most important matter. The wear which took place was mostly in a vertical direction, and the resulting error in the

work was small. The handiness of the lathe during its whole life caused a saving in the workman's time, and in most cases more than counterbalanced the heavier cuts that could be taken on the English type of lathe. The whole matter of efficiency really rested on the way in which the tools were used, and the best results could only be obtained by working either type in the way the designer had in mind. With regard to one or two of the little points raised by previous speakers, he might mention, with regard to the danger of cross-threading on odd pitches, one lathe which had an excellent method of getting over that difficulty. In the Hendey-Norton lathe, when the end of the cut was reached, a lever at the side of the carriage disengaged the entire screw mechanism, and allowed the carriage to be brought back by hand and the clasp nut replaced without risk, because the guide screw was stationary while that was being done.

With regard to the roller feed on hexagon or similar turret lathes, one form had not been referred to. This was embodied in the lathe made by Messrs. Warner and Swasey, in which a lever operated the chuck, and with the same action simultaneously actuated the roller feed that moved the rod forward. One advantage was that it would move the rod up equally well, whether the machine was running or stationary. He would like to support what previous speakers had said as to the indebtedness of the Institution as a whole to Mr. Ashford for his valuable Paper.

Mr. H. M. ROUNTHWAITE said that the question of the best type of machine for any particular class of work should not be settled without taking into account the working arrangements prevailing in the factory. In many large marine-engineering works the apprentices would number up to fifty or sixty, and in some a large part of the machine work was done by these lads. There was a constant succession of boys passing from machine to machine up through the shops, and they scarcely got the "feel" of a machine before they were promoted to a larger one. The machines probably never did the best work of which they were capable, for want of small adjustments which the boys had not learned to make, and

(Mr. H. M. Rounthwaite.)

about which the millwrights were too busy to concern themselves. It therefore appeared to him that, for this reason—and for the further reason that there was little repetition work about marine engines (which were rarely made for stock)—the expensive, delicate, and complicated automatic or semi-automatic machine was not nearly so well suited for use in such factories as was the old-fashioned sort of " Jack-of-all-trades " English machine. Their American friend would no doubt tell them that such procedure was factory mismanagement, and was quite out of date, &c. This might be quite true, but he saw no immediate likelihood of change in this country.

. As regarded lathe beds, he objected to the raised **A**-shaped ridges—which were merely survivals from the time when, in America, the bed was of timber and carried on its upper surface iron guide-bars fixed by wood-screws—because they were so easily dented and damaged and so troublesome to true up again. He quite agreed with Mr. Schönheyder (page 345) that the use of a screw which could only be turned by means of a screw-driver, for adjusting slides was thoroughly bad design. He also thought the adjusting arrangements shown in Figs. 8, 9, 10 and 11 (page 266) might be similarly described ; they were all much inferior to the longitudinal wedge.

Mr. OSCAR HARMER said he had been very interested in the Paper, and the discussion which had arisen out of it. He was present as a tool maker, and came to learn. He did not think that discussing the details of machines was very profitable to a tool maker or to a purchaser, because it was likely to degenerate into a contest between the designers of the different machine-tools dealt with in the Paper. Every man in the country, and every man present, wished to know how much work could be got out of a machine, and how good the work was, and for how little money he could have the machine and its product ; and he did not care whether the man selling the machine wore a good coat and a silk hat, or did not. It did not matter to the user what were the details of the machine offered ; he was less interested in that than in " What will it do, what will it do well, what will it cost me

to do this work, and how good will the work be, and is there a dividend for the shareholders at the end of the business? If there is, we trade." The Paper dealt with a very large and wide range of machines. It was really an excellent Paper; he had read it through and through. He had been familiar with it in furnishing details of a large number of the machines for the design of which he was responsible, and he was able to realise what a vast amount of work the author must have had. His object in coming to the meeting was to learn what were the requirements of machine users, to find out their requirements, to get to know the conditions which buyers wanted filled. Once having obtained that information, the rest was easy if the designer were a capable one. The difficulty mentioned by Mr. Deakin (of buyers declining to supply information) was a real one; some users of machines would not even now tell the designer what they wanted them for. If a machine maker said he could do this or that in a certain given time with his machine, the reply was sometimes received—" You can do it in your shop perhaps; we know some of you can, but we cannot," which seemed a high compliment to the tool maker. On such occasions, however, the user was apt to call in question the statement of performance.

The first speaker at the previous meeting, Mr. Wicksteed, in referring to a design, had criticised the feed motions (page 311). As the speaker who had just sat down stated, all engineering was a question of compromise; it was not a question of which thing was perfect, but which thing was good enough, and that which was good enough would sell every time. He believed that Lang was the first to introduce to any extent into Europe the handle feed-motion. Their feed motion was satisfactory : he himself had worked a number of their lathes and a large number had been working under his supervision. However perfect something else might be, the motion in question was good enough, and while it satisfied the requirements and was cheap, it would do. It was a compromise. They could not expect to get anything absolutely perfect, though a good many people aimed at it.

Another point which Mr. Wicksteed questioned was " that turret lathe methods were taking the place of the ordinary lathe methods,

(Mr. Oscar Harmer.)

in a similar manner to that in which milling had replaced slotting."
He maintained that was true, although Mr. Wicksteed criticized it
very severely and gave an illustration of an extreme case, namely, the
milling of a marine crank-web in proof of that contention, Fig. 112
(page 313). He thought that milling such work as wheels, profile
depressions, typewriter parts, sewing-machine and gun parts was
what the author referred to, rather than the extreme case given by
Mr. Wicksteed. In America there were many factories building six
milling machines a day, one of which he knew : but where could be
found a shop in this country which built six slotting machines a
week ?

He was very much disappointed that Mr. Donaldson, from
Woolwich Arsenal, did not give some of his experience in the use
of turret machines. His experience at Enfield would also have been
most welcome. Some eighteen years ago he, the speaker, built a
large number of automatic screw-machines for Enfield, and they
were running there today. He heard one gentleman say that if
they put heavy work on American tools that they would " dither "
out of the shop (page 326). But, notwithstanding that, the machines
he referred to were running there today, and did good work. Since
Mr. Donaldson had been at the Arsenal more machines of that type
had been fixed, which he took to be evidence that, as a business
man, he was fairly satisfied with them. He would like, seeing that
the author desired it, to go into the details of the machines which
were referred to, if the President had not reminded him that it was
very late. But he would refer to the question of the roller-feed.
As he was a bit of a sportsman, he was quite prepared to take up
Mr. Deakin's challenge. He would undertake to operate, and feed
the bar on any turret lathe, the bar of which was fed ordinarily with
the roller feed, the same distance, in less time, than Mr. Deakin
could do with the roller feed. No one had any right to attach to
any machine any device which added to the cost or the complication,
unless it accomplished one of two things : either it must give more
work of the same quality for the same money, or better work, the
same in quantity, and of better quality, for the same money. Only
one of those could be a justification for the added complication. He

maintained—and he had had considerable experience in actually operating turret lathes—that when he opened the chuck he could pull the bar out in one-third of the time—though that was not his guarantee—that Mr. Deakin could feed the bar by the roller feed. It was not a question of feeding the bar; the trouble was in knowing when to stop it. It could be used as a battering ram: one could knock the saddle off the end of the bed with it; he had seen it done.

He would like to call attention to another point in reference to the design of some of the machines. The author stated (page 290) that the lathe there referred to had forty rates of feed relative to the spindle. He maintained that, from an extensive experience, forty rates of feed were unnecessary. His contention was that three were ample for that type of lathe. Why forty should be considered good, when three were enough, passed his comprehension. With regard to the cross-turret lathes (page 292), shown on Fig. 76, Plate 37, he hoped the Meeting would bear with him while he made an explanation with regard to them. Over twenty years ago in America the first turret lathe he saw was one brought from Zurich in Switzerland. It had a turret of the mitrailleuse form, and he met the man—a Swiss—who brought it, and had some considerable discussion about it. It was a hand-screw machine. There were two objections raised against it, one that it failed structurally, the reason being that the turret was sliding over the lock bolt. The other objection was that it failed in use, because it was impossible to get any practicable sized tools in it. They had to use hollow mills, and it was difficult to set them to do good accurate work. The inventor of the machine went back to Switzerland, and undertook to overcome the difficulties pointed out to him, from which the first lathe suffered. Thereupon he did exactly what was described in the Paper. Instead of the axis of the turret being in line with the spindle, he put it across the bed, the tools radiating from the turret, like a big wheel. No doubt he got plenty of tool room in that way, and he got his lock bolt travelling with the turret. He seemed to overcome every objection. But, in working, even that failed, and he would tell them the reason. When the lathe was turning, all the driving power forced the turret away

(Mr. Oscar Harmer.)

from its seat. The inventor was not a wealthy man, and the objections raised on that altered machine were the means of his becoming bankrupt. The lathe was then taken up by a man named Robins, who had a small engineering shop. He re-designed the lathe, got some money advanced on it, and put it on the market. With the new design the power of the lathe no longer forced the turret away from its seat, but was transmitted to the lock bolt, and had to be taken care of by the same, which was very bad practice; he never saw a good job produced by that machine. Now it seemed that the machines having a mitrailleuse form of turret and a cross turret had been re-invented; designed by people who did not know the history of the turret lathe, and did not know why some of the things which had been invented and tried had not succeeded. He felt very strongly on some of those points, and wished to emphasize them. There had been brought to this country a multiple-spindle automatic, which was held out as being new; such was not the case. There was a multiple-spindle automatic designed by himself at work in this country, which was made in Scotland. Those machines had not four spindles but seven. There was a batch of twelve automatics which were built by himself in Pittsburg twenty-two years ago, and they were at work in America today. Yet those things were re-invented and brought out as new. That sort of thing was constantly done, and it made a man tired. He was quite sure that many of the devices and parts of machines were being re-invented; many American as well as old English notions were being brought up again as new. Of course there was a certain amount of fame attached to these inventions, but as he said, it made a man weary when he knew the history.

Mr. H. F. L. Orcutt said he was averse to trespassing on the time of the meeting at this stage, and would therefore take his cue from Mr. Harmer and omit technical details, although he would like to mention one, namely a point with reference to the centres used in the English lathes, as compared with the American practice. The American practice followed 60° centres as a rule. Many manufacturers who had made tests in that line would agree that it

could be proved that 10 to 20 per cent. more work could be turned out with 60° centres than with an ordinary 90°, such as was commonly used in England. That was a point well worth bringing out. He knew the members—particularly the users of machines—were specially interested in those matters; and he thought they were indebted to the author for forming as it were a catechism (pages 261-2-3), which would be useful in selecting machines on their merits. The author had had compliments enough paid him, but notwithstanding that he, the speaker, wished to add his.

There were several types of machines which had not been mentioned in either the present discussion or that of last week, but which were well worth calling attention to. The work suitable for turret machines must always be taken into consideration by anybody who had a variety of work to do. One was the Gisholt machine, which was one of the first types of turret machines for dealing with heavy castings. It might be regarded as really the father of the large type machines, and must share honours with the Jones and Lamson. Both those makes had been largely imitated and copied by various makers. Another type was a small automatic with single tool-holder at the end of the slide. There was no revolving turret in that machine. It was 'a very simple, efficient, and inexpensive machine, especially for work where no threading was called for. Another very important type was the vertical-turret machine, which he thought deserved much more attention from manufacturers than it usually received. It was, in fact, simply a turret lathe stood on end. It had many advantages which it was impossible to embody in the horizontal machines, and the most important of which were rigidity and speed in working. Another type, quite recent, was that invented or designed by Mr. Conradson, and exhibited at the Paris Exhibition. It opened the eyes of many as to the possibilities of turret-machine work, but perhaps the machine did not embody finality for very heavy turret work. Yet it did such heavy work that the turret had to be moved by power; it was too heavy to be moved by hand. The only other point he would refer to was the Taylor White crosses for turning, which were shown at the Paris Exhibition. Many imitations had been attempted, and many approaches to its

efficiency had been made since then. The ordinary turning-speed of a lathe might vary from 34 to 40 feet a minute at the highest. The Taylor White high-cutting speed process resulted in a speed of 150 feet per minute. That was a point which he thought should be seriously considered by lathe makers. It was astonishing what could be done by ordinary turning-lathes with these specially prepared tools.

The PRESIDENT said that the time had arrived when it was necessary to close the discussion, and to ask Mr. Ashford to reply to the points which had been raised. He regarded the discussion as having been a most excellent one, and yet it by no means exhausted all the points which Mr. Ashford had brought forward in his very able and interesting Paper. He hoped therefore that members who had not had the opportunity of speaking would, if they had any contributions to make, send them to the Secretary in writing, so that they might be incorporated in the printed Proceedings. He thought all present would feel that the discussion had been very materially aided by the kindness of the makers who had sent the two machines and the numerous admirable examples of work which were exhibited. Before asking Mr. Ashford to reply, therefore, he would request the members to heartily thank those gentlemen for the trouble they had taken.

Mr. ASHFORD, in reply, said the main object he had in preparing the Paper was to promote discussion on the particular class of machinery he had dealt with. That object, he felt, had been achieved. As the hour was late, he would not attempt to reply in detail to the various remarks which had been made, but would make his rejoinders to some of them in writing (page 362). Several remarks had been passed by members, which had received suitable replies from others during the discussion. When that had been so, his reply would not be extended by reference to them, unless he felt an additional opinion was desirable. He could not allow to pass unnoticed a remark good-humouredly made by Mr. Wicksteed to the effect that a certain illustration, Fig. 45 (page 280) had perhaps been taken by the author from a text book fifty years old. He did

not think Mr. Wicksteed realised the full import of those few words. The drawing in question might certainly be relegated to a place in ancient records without loss to the present generation of tool-makers. The really unfortunate part of the matter was, that it had been taken from the drawings of a lathe made about three years ago. The remark therefore became a criticism of certain conservative tool-makers. It was only fair to English tool-makers, however, to say that practically all the best of them had stowed away such designs in the bottom drawer of the drawing cabinet. The chief reason that it appeared in the Paper was to throw into comparison the two methods of locking the loose headstock and to bring up the point that he had been making in the text, namely that any adjustments or movements should be possible without the use of the loose spanner.

Speaking further on the question of loose headstocks, he urged that a method of locking the centre-slide, which tended to force the centre out of its true position, could not be good, but that such a design as Fig. 49 (page 280) would be better practice. Referring to cross adjustments for loose headstocks, he felt very strongly that the working accuracy of a machine (as for instance, the linability of a lathe) should not depend upon the operator, and therefore a provision for throwing over the back-centre for the purpose of turning tapers was objectionable. He agreed with Mr. Chambers and Mr. Vernon that an adjustable guide-bar on the back of the lathe, especially if fitted with some accurate measure of the degree of taper, was by far the more satisfactory method of obtaining tapers. Some speakers objected to this back bar by saying that short tapers could not be obtained, but no doubt the method of holding and adjusting it could be modified to make it possible to turn all such tapers as were usually wanted.

He thanked the members for the kind way in which they had received his Paper, and expressed his pleasure that the discussion had been of such a decidedly practical nature. [See page 362.]

Communications.

(See Plate 52.)

Mr. G. H. BANISTER, in continuation of his remarks at the Meeting (page 336), wrote that the design of tools for machining the pipe-axle-box illustrated in Fig. 116 (page 357) was prepared by Messrs. Alfred Herbert of Coventry, and the work was carried out on a powerful lathe of their design, known as their No. 6 hexagon-turret lathe, Plates 36 and 52. The pipe-axle-box was made of hard phosphor-bronze, and the work to be done by the tools was severe, both on account of the hardness of the metal and the hard scale on the surface of the casting. During the whole operation the cutting edges were plentifully lubricated with lard oil pumped from and returned to the trough below the machine. These pipe-axle-boxes had to be bored with a considerable degree of accuracy, and must be true to length. As the hole was coned and the outer form of the pipe-box such that the end faces of the box must be in correct relations to projections cast on the outside, care must be taken that the cone itself was bored to suit the faced ends of the pipe-box.

The operations to be performed were as follows :—(1) The casting was held in a 3-jaw chuck and a rough boring bar, provided with cutters separately held in the bar by set screws ; Fig. 118 (page 358) was inserted, breaking up the surface and rough boring the hole.

2nd operation.—A second similar bar, Fig. 119, was then entered, which completed the rough boring and removed in great part the ridges left by the first operation, the cutters in this second bar fitting in the spaces between the tools of the first bar.

3rd operation.—An ordinary cutter-bar with taper cutters, Fig. 120, was then inserted for the purpose of removing all ridges left by the former operation.

4th and 5th operations.—These consisted in the insertion of rough and finishing taper reamers. The cutter teeth of the reamers were of special form and were left-handed, so that as the lathe ran in the usual direction the cutting edges did not tend to " gather " and pull the job harder on the cutters, Fig. 121. The boring bars of the

Fig. 116. *Gun-carriage Pipe-axle-box (Phosphor bronze).*

Dots indicate parts machined.

Section on A B.

Fig. 117.

*General Arrangement of Tools
for producing Pipe-axle-box
on Hexagon-Turret Lathe
(No. 6).*

Typical set of Tools for Boring and Turning Pipe-axle-box. Fig. 116.

FIG. 118.

FIG. 119.

FIG. 120.

FIG. 121.

FIG. 122.

first three operations were supported at both ends, the outer end of the bar being carried in a steady bush in the lathe spindle, but the coned reamers were supported in a floating holder, so that the reamers might readily adjust themselves in line with the axis of the pipe-axle-box.

During the above operations the pipe-box had been turned, and faced at one end by tools carried in a square turret of the lathe saddle, Fig. 117.   The above completed the first series of operations. The pipe-axle-box had now to be turned in the part previously in the chuck, and screwed and faced at that end.   To enable this work to be done the pipe-axle-box was then held on a special expanding arbor, Fig. 122, which, during the operation of tightening, also drew back the face of the pipe-box (turned in the first series of operations) into contact with a bush held in the 3-jaw chuck, thus registering the pipe-box in relation to the stops of the slide-rest.   The outer end of this arbor was carried in steady bushes on the faces of the turret during the subsequent operations.

6th operation.—Rough turn the three diameters of the pipe-box with the tools indicated in Fig. 117.

7th operation.—Finish turning.

8th operation.—Cut screws for back of thread on pipe-axle-box with tool held in lathe turret, and chase the thread with chaser held in the turret.

The pipe-axle-box was then completed.

Mr. E. J. CHAMBERS, in continuation of his remarks at the Meeting (page 323), wrote that he thought the scope of the Paper did not justify its title.   The latter part of the title correctly indicated the class of tools dealt with in the latter part of the Paper; but the very limited notice of light lathes, including the particular makes in this country, did not justify the heading.   If a Paper professed to introduce any particular subject, it ought to state and fully illustrate both sides of the question.   A more correct title for the Paper would have been " English and American Automatic Screw Machines."   In that case the author might have said even more about some of the American tools, and if the Americans beat us in this particular

direction, he was prepared to try to recover our position by further effort; but he often read exaggerated and misleading reports of the superiority of American engineering work. He pointed out there was an endless number of special machines and processes entirely of English design at present in operation in our workshops, which he considered far ahead of anything at present schemed by Americans, but these were usually carefully confined to the places where they were so usefully employed.

Mr. MAX R. LAWRENCE wrote that a feature of design, which he had found to be not only very useful but almost essential for his work, was a vertical turret at the back of the cross slide of a chasing capstan lathe, in addition to the flat hexagon turret. Many of the parts he had to machine required the whole of the tools on the turret, and in addition required three tools on the cross slide, say a forming tool and parting tool at the back and chasing tool at the front, which necessitated a hinged parting tool. From this idea developed the arrangement, which he was making, of a vertical turret with four places for tools to fix at the back of the cross slide. This would hold a parting tool and three form-tools, in which he found he could build up nearly all, if not quite all, his expensive form-tools out of a series of simple-shaped tools, which came into action in rotation instead of forming the whole piece at once. This arrangement working on a hard quality of phosphor-bronze saved a considerable amount of time, as a broad form-tool took longer than three tools of one-third the width. It was also less liable to disturb the work in the chuck in the case of fragile castings.

Mr. JOHN MILEY wrote that every engineer ought to find plenty of food for his mind by comparing the tools he used with what had been described in the Paper. He proposed to confine his remarks to light lathes, not having had much experience with automatic lathes and screw machines. His opinion of spindles agreed with that of the author. On the question of bearings he thought one could not have a better design with a mild steel spindle and phosphor bronze bushes than Fig. 3 (page 265), and his experience taught him

to avoid cone-bearings ; but if the latter were used, the cone should be about one in four to prevent the possibility of locking in the bearing.   The adjusting or gib strip shown in Fig. 10 (page 266) commended itself to him for slide-rests.   He had used one very similar for many years, which had proved very satisfactory, all the strains being taken on metal to metal, and not by tension in small screws.

In regard to lathe beds he much preferred the English section, Fig. 12 (page 267), for most classes of work made with square edges in place of Vs.   He considered Fig. 123 a better section than the one shown in the Paper.   All the motions of a lathe he thought should be under the control of the workman, without the use of spanners.   He strongly recommended the traverse gear, Fig. 29, Plate 23.   The worst drawback in the construction of a lathe from the standpoint of output would be found in the driving cone.   There were not enough changes of speeds, and there was too big a jump between the steps of the cone pulley ; and in double gear the belt had far too little grip, the average power of a 10-inch centre lathe being a $3\frac{1}{2}$ inches wide belt on a 10-inch diameter pulley running 120 revolutions per minute.   This power wanted increasing by about four to one to be equal to a new high-speed tool steel which he had cutting at 50 to 70 feet per

FIG. 123.

Opening 1.9 long
Metal between 1.0 long

0   6   12 Ins

minute.   It cut $\frac{5}{16}$-inch deep with geared traverse of 22 revolutions per inch.   He thought one could not get the useful work out of this new tool steel, without a radical change in the driving gear of a lathe headstock.   Here was a splendid opening for improvement, which would increase the economy of every lathe, by making it equal to the cutting tool and avoiding loss of cutting speed when changing diameter of work.

Mr. JOHN WEBSTER, of Crewe, wrote that he considered there were many new, ingenious, and interesting parts described in the Paper ; at the same time they involved so many complications, that the cost of repair must be considerably more than that of the old-fashioned

(Mr. John Webster.)

substantial simple tools. There were so many toggles, joints, clutches, wheels, springs, &c., in such confined spaces, that there was not room to make these sufficiently strong to be of long duration; and in such case when they became a little worn he was afraid they would prove unsatisfactory. There was certainly an advantage in turret lathes so long as they kept in order, but in his opinion there was less advantage than some makers claimed for them. He had had experience with two, Jones and Lamson's, and several of Herbert's turret lathes, which appeared to be good substantial tools, but he had never seen them taken apart. An expert, who came with the former tools to show how to work them, did not complete any one job in the time stated by the makers. These lathes were certainly very useful for many pieces of work where a sameness was required, but for straight or taper work they did not equal the well-known four-spindle lathes.

With regard to paragraph (a, page 261) he had known spindles and bearings, similar to Fig. 1 (page 265), Whitworth lathe type with hardened steel cones and spindles, to run thirty-five years without being taken out for repairs. He also remembered one of Batho's lathes with white metal steps and soft spindle, similar to Figs. 4 and 5, to remain in its place for thirty years without having any repairs. In both cases they had been worked by careful and attentive workmen. He liked the design shown in Fig. 3.

With regard to automatic machines, although his experience with one on trial had not been satisfactory, yet he believed it was possible to design a good automatic machine. Almost any motion might be attained by cams; for instance, the intricate and accurate movements of lace machines were nearly all produced by cams.

Mr. ASHFORD, in continuation of his reply (page 355), wrote that Mr. W. W. Marriner, in the course of his remarks (page 328), gave expression to the following words—" Convenience was a great factor in economy." Throughout the writing of the Paper, the idea of convenience and handiness as an especial need in a modern machine-tool was prominent in his mind, and he thought it possible that when the feeling of this need received direct expression, machine-tool

makers in this country would give that side of the question more consideration.   Conversation that the author had had with several tool-makers, since the reading of the Paper, went to show that they were earnestly considering the possibility of modifying designs, so that while retaining the more important features of the English lathe, the machines should yet be second to none in matters of handiness.

As remarked by several members, the design of these machines was a matter of compromise ; but, to quote from Mr. Harmer's remarks (page 349), having " learnt the requirements of machine users . . . the rest was easy, if the designer were a capable one." Summing up the discussion, the general opinion seemed to be that convenience and handiness, as called for in the lettered paragraphs set forth in the early part of the Paper, were desirable, providing that they could be obtained without sacrificing the general stiffness, strength, and other good features, such as the slide-rest, of the English lathe.   Mr. Harmer suggested that the user was not interested in the details of the machine he might have to buy, but that his sole consideration was " what will it do . . . what will it cost to do this work."   It seemed to the author that the buyer who failed to consider the details was foolish, for, without doing so, he had absolutely no guide as to what that machine might cost in the future for repairs, and how soon it might be necessary to write it off as scrap iron.   Without a consideration of details, he had absolutely no safeguard in this respect but the reputation of the firm from whom he bought.

Mr. Bentley (page 345) brought out a fact which users sometimes failed to realise—namely, that a given weight of metal might be removed, when turning, by either a heavy cut at slow speed, or a light cut at quick speed.   It might be added, that in light lathe work the amount of cut was often regulated by the strength of the material being turned, and they were rather forced to the conclusion that in light lathes the quick-speed machines with light cuts would do the most all-round work in a given time.   There was a still further point affecting the question of output that he would like to make. The length of time that the cutting tool retained its edge was an important factor in the cost of machining, and the cooler the tool

(Mr. Ashford.)

was kept the longer it retained its cutting edge. Why, therefore, did they not fit their ordinary lathes with a pan and pump so that a copious flow of either suds or oil might be brought to the tool, thus dispensing with the miserably inadequate old-fashioned drip-can ?

With regard to the feed-change mechanisms, the point made by Mr. Wicksteed (page 311) in reference to the Archdale change-gear was good. It would be an improvement to modify it so that the speeds changed in regular order as in the Panhard motor-car gear. Several members considered that too many changes of feed were a disadvantage. That was so, if the machine was to be used for sliding and surfacing only, but the criticism was scarcely a fair one as applied to the machine illustrated on Plates 31 and 32, which was also intended to do screw-cutting.

The point raised by Mr. Vernon in discussing clause (e, page 261) when he referred to the inconvenience that was experienced when cutting odd threads, through having to keep an eye on chalk marks coming round, was a good one. He had pleasure in accepting Mr. Vernon's suggestion that the following should be added to the paragraph : " and it should not be possible, when re-engaging, to cross-thread the screw." Mr. Bentley called attention to the Hendey-Norton method of stopping the screw (page 347) by throwing out a claw-clutch before disengaging the clasp-nut, and he implied that cross-threading might be avoided thereby. By way of preventing a misconception in this matter, he (the author) would point out that the mere stopping of the leader screw would not prevent cross-threading, because the lathe spindle might still be rotating ; and when re-engaging the claw-clutch there was no guarantee that it did so in the same notches as before. If however the claw-clutch were made so that it could engage in one position of the mandrel only, and the saddle traversed backwards by the leader screw, this method might be a way out of the difficulty—if not, perhaps the best.

In the Hendey-Norton machine, if the clutch were used to reverse the traverse of the saddle, thus returning the tool to the starting point without releasing the clasp nut, the thread might be correctly picked up without any doubt. If however the thread were odd, and the leader screw merely brought to a standstill, the clasp nut

released to allow the saddle being traversed back by hand, and the clasp nut re-engaged before starting the screw (a method which seemed to be implied), *it was possible to cross the thread.*

Mr. Harmer strongly condemned the introduction of automatic roller-feed and turret-revolve on the heavier class of turret lathes (page 350), contending that just as much, if not more, work could be done without them, and that therefore the additional expense in putting them on was not justified. Some time ago the author, when visiting an exhibition at which some of these machines were at work, entered into conversation with a mechanic who was operating a large hexagonal-turret lathe without the mechanism referred to. He stated that to work the machine was most fatiguing, and that the continual pulling round of the turret was—to use the man's own words— " enough to pull you inside out." In a matter of this kind it was surely economical to make work easy, even if it raised the cost of the machine. The argument against roller feeds—that they would not act unless the machine was running—was not a sound one, because, firstly, it was usually when the machine was running that the bar was wanted to feed forward, and secondly, the roller feed could be made to work either when the machine was still or running, as was the case in Warner and Swasey's machine. It would be a good thing, on heavy turret-lathes for bar work, to put a self-centering chuck at each end of the spindle, both of them working with the same handle movement.

Mr. Austin, when discussing the design of lathe beds, made an excellent suggestion, that felt pads should be fitted at each end of the saddle to sweep away dirt and keep the bed-surface well oiled. The new design of lathe-bed, introduced by Messrs. Lang and Sons, and brought before the meeting by Mr. Marriner, seemed to be well thought out, and likely to eliminate the cross-twisting of the saddle. The wedge gib-strip used upon it was also good, if not superior to the others illustrated.

He agreed with Mr. Chambers (page 325) that with self-opening dies on turret lathes, if they were well made and properly used, any desired degree of accuracy might be obtained. That gentleman's remark (page 359) that the contents of the Paper

(Mr. Ashford.)

did not justify the title, and that the latter should be modified as he suggested, could not be accepted by the author, considering that the greater part of twenty-two pages of matter and nine Plates were given to light lathes, and only thirteen pages of matter with eleven Plates to automatic screw-machines.

In reply to Mr. Schönheyder he regretted his inability to give the name of the maker of the Swedish machine illustrated on Plate 35.

Since the preparation of the Paper the following improvements in the machines dealt with have been notified.

The Wolseley Cross-Turret Lathe, illustrated on Plates 37 and 38, has had its stop mechanism remodelled. The essential points of the new arrangement are illustrated in Fig. 124, and the description of its construction and working is as follows.—On the extreme left, near the headstock but towards the rear of the machine, there is a lever fulcrummed upon the lathe-bed. The lower end of this lever engages a rod which actuates a throw-out and reversing clutch

FIG. 124.

Lever Stop-Gear for Cross-Turret Lathe (Wolseley), Plates 37 and 38.

of the claw type. To its upper end six rods are attached, having upon each a pair of adjustable stops. These rods lie along the machine over the top of the turret saddle upon which, in a suitable position to engage the adjustable stops, there is a stop bar. As in other machines using a series of bars for checking the automatic traverse, a device for putting all the bars out of action, excepting that one which corresponds to the tool in use, is necessary. For this purpose, a series of lifters are placed within holes drilled in the saddle above the turret shank, and their lengths are sufficient to elevate the rods so that normally the stops may not engage the stop bar upon the turret saddle. The turret shank has a number of depressions cut upon it in positions corresponding with the various tools, so that as a tool comes into use, the lifter that corresponds with the tool drops into the depression which has come into position beneath. Thus the right rod is lowered, so that the stops upon it may engage the stop bar. In the illustration, the lifters and the depressions in the turret shank are numbered with the same figures.

FIG. 125.

Automatic Cutting-off Slide for Cross-Turret Lathe (Wolseley), Plates 37 and 38.

Inches 12   9   6   3   0   1 Foot

(Mr. Ashford.)

An automatic cutting-off slide has also been added to the same machine, Fig. 125 (page 367). The feed motion is obtained from a back shaft through the medium of an inclined spindle and two pairs of helical gears.

FIG. 126.

Speeding Gear for Automatics (Wolseley), Plates 41, 46, and 47.

Driven by Friction Discs

Drives worm-wheel that revolves turret feed cam.
Slowly for Cutting.
Fast for turning turret and for advancing tools to work

0   1   2   3   4   5   6   7   8   9   10 Inches

The automatic-screw machine, illustrated in Plates 41, 46 and 47, has had a portion of its mechanism modified. The drive to the cam shaft was there shown to be from a pair of friction discs, through a set of bevel gears, and a claw clutch which was used to put a reducing mechanism into or out of action as required. That gear was found to work perfectly, but it was very noisy after it had been in wear for a time. It had, therefore, been substituted by the mechanism illustrated in Fig. 126. In this, the spindle that is driven by the friction discs has upon it both a worm and a helical-gear wheel. These respectively gear with a worm-wheel and a second helical-wheel. A reference to the plan will show how these gears are arranged, so that by a movement of a double claw-clutch, either may be caused to drive a second worm which revolves the turret feed cam, etc. These two gears are proportioned to give the two main changes of speed for feeding the turret, the slower one through the worm-wheel for the cutting feed, and the quicker one through the helical gears for changing the position and advancing the tool to the work.

The Institution of Mechanical Engineers.

PROCEEDINGS.

MARCH 1901.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 15th March 1901, at Eight o'clock p.m.; WILLIAM H. MAW, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following fifty-one candidates were found to be duly elected:—

MEMBERS.

ANDLAU, WILLIAM FERDINAND VON,	Gibraltar.
BANISTER, ALAN NEVILLE,	Norwich.
BLAKE, MATTHEW,	Greenock.
DUFF, EDWARD JAMES,	Widnes.
ERICHSEN, FREDERIK OLE,	London.
HOWE, HENRY BRYANT,	Sydney.
LESLIE, WILLIAM,	Mundaring, W. Australia.
MACLURE, WILLIAM GEORGE PERCY,	Manchester.
MCLAREN, WILLIAM ALEXANDER,	Leeds.
MCQUEEN, JOHN CHARLES,	Barbados.
NAKAJIMA, YOSOHACHI,	Glasgow.
SIMMONS, GEORGE THOMAS, Fleet Engineer, R.N.,	Chatham.
SMART, ROBERT HOWIE,	Greenock.
STENNING, HENRY ALEXANDER,	Carnarvon.

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WARD, JOHN, ... Para, Brazil.
WARRINER, ROBERT, ... London.
WEBSTER, FRANCIS JOHN, . . . Doncaster.
WRIGHTSON, WILLIAM PERCIVAL, . . London.

ASSOCIATE MEMBERS.

ASTON, EDWARD BACKLAND STUCKEY, . London.
AYERS, FREDERIC GORDON, . . . Adelaide.
BENN, WILLIAM WILTSHERE WENTWORTH, Aberdeen, N. S. Wales.
BRESSEY, CYRIL EDWARD, . . . Manchester.
BUCHANAN, WILLIAM ERNEST, . . Simla.
BULLOCK, RICHARD CECIL, . . . London.
CARNEGIE, WILLIAM, ... Woolwich.
HEY, JOHN, ... Leicester.
HIGGINBOTHAM, GEORGE, . . . Manchester.
HOGG, JOHN THALLON, . . . Durban.
HOPKINSON, ALLEN HAIGH, . . . Huddersfield.
HUGHES, GEORGE WILLIAM, . . . Birmingham.
LARKIN, FREDERICK STANLEY, . . London.
MACKAIL, JOHN HENDERSON, . . Dundee.
MANNOCK, JAMES JACKSON, . . . Oldham.
MASSÉ, ROBERT WILLIAM HENRY JOSEPH, London.
PECKETT, ARTHUR, ... London.
PYE, JOSEPH HARGER, ... Clevedon.
SHAW, GEORGE, ... Barbados.
SIMPSON, NORMAN DE LISLE, . . Barbados.
SMYTH, JOHN MCFALL, . . . Keighley.
THOMAS, ARTHUR LLOYD, . . . Pontypridd.
UNWIN, MAURICE EVERETT, . . . Sheffield.
WALFORD, FREDERICK, . . . Bankipur.
WINSTANLEY, FRANK ATHERTON, . . Rotherham.

GRADUATES.

BOULTON, JOHN HOWARD, . . . London.
FREEMAN, BRYN, ... Leeds.
HORSNELL, THOMAS, ... London.
MAW, ROBERT LEWIS, ... London.

Pickles, Thomas Sykes, . . . Manchester.
Ruddle, George William, . . . London.
Senior, George, ... Chatham.
Williams, Stanley Victor, . . London.

TRANSFERENCES.

The President announced that the following three Transferences had been made by the Council :—

Associate Members to Members.

Mount-Haes, Andrew, . . . Kalk, near Cologne.
Moylan, William Morgan, . . Calcutta.
Penn, William Cooper, . . London.

The following Paper was read and discussed :—
"Combined Trolley and Conduit Tramway Systems;" by Mr.
    A. N. Connett, of London.

The Meeting terminated at a Quarter to Ten o'clock. The attendance was 143 Members and 128 Visitors.

COMBINED TROLLEY AND CONDUIT
TRAMWAY SYSTEMS.

BY MR. A. N. CONNETT, OF LONDON.

In many cities where the overhead trolley is or will be admitted on surface tramways, there often exists a street or a central zone where it is or will be expressly prohibited. Again, other cities prohibit absolutely the trolley within their limits, but penetrating lines from the suburbs come to the limits with the trolley ; and from there a change of cars must be made to enter the city, or else the same cars must be equipped so as to be able to use another mode of traction. The general engineering problem in these two cases is about the same. Broadly speaking, it is that the electric motors, with which the car is equipped, must be furnished with current from a source other than the overhead wire along a part of the route. There is no one well-defined method upon which engineers are agreed as being the best for solving the difficulty. It is natural that this should be so, because local conditions constitute such an important factor that each individual case must be carefully studied by itself : so that what would be a correct solution in one place might not be justified in another. The three means of solving the problem are by :—

1. Accumulators.
2. Surface contact.
3. Open-slot conduit.

The first two systems it is not the purpose of the author to discuss. As the result of his experience with accumulators he would advise that, if in a given instance their installation should seem to be advisable, the contract should be drawn in the form of a rental for

the batteries, on the terms of paying a fixed sum per automobile car-mile for their use; this sum should include the entire cost of maintenance and renewal of the batteries for a fixed period. Penalties should be inserted in the agreement for each trip lost through failure in working of the batteries; and their electrical efficiency should be guaranteed up to a certain standard, below which the excess waste of energy should be paid for at an agreed rate per ampère-hour. This method has been employed in France and Germany with good results. It seems the best yet devised to protect the user from a poor form of battery for a given work, and at the same time to insure the maintenance of the batteries in the best possible conditions; this last proviso is to the evident advantage of both buyer and seller. The batteries should be placed under the car-body if possible; if this is not done, the acid fumes are disagreeable to passengers, and the effect will be a diminution of receipts and an accession of complaints.

If surface-contact should be decided upon, the choice of one of the many systems will require careful study. If the number of cars using the portion of track to be equipped with the selected system is large, and the length of such portion is comparatively small, it will be found that the cost of the equipments for cars carrying the magnets will be relatively excessive, and that the employment of a magnetic switch for each contact-point will be much cheaper. If the surface-contact portion of a line should be of relatively great importance, this conclusion as to first cost might easily be reversed. The vital questions of working, maintenance, and safety, have to receive the most careful consideration, with the disadvantage that there is at present little to be learned from experience on actual working lines, which are either too few or too recently started.

There should be no hesitation about adopting the conduit, where financial and constructional conditions make it possible, for this plan has proved itself to be workable. It has passed entirely beyond the experimental and uncertain period, and can now be adopted without hesitation for the propulsion of electric tramway cars. It can fail completely; but even partial failure will be the fault of either design or construction, or of both.

The problem of adapting the plough and track mechanism, so as to change from the overhead line to the conduit system or vice versa, has been satisfactorily and carefully worked out on several different general principles. In America, where the conduit has been generally adopted in the cities of New York and Washington, the problem of a mixed line has received little attention. In Washington, on two unimportant trolley-lines, the cars run directly into the city on the conduit tracks ; but the manner of making the change is too crude to be worthy of attention. On the Continent there are a number of examples of this kind, and they are all worthy of attention, the problem having received in each case careful study. This, in the author's opinion, is only one instance in several, where European tramways offer now a much more fruitful field for study than American tramways, especially to an engineer called upon to establish a tramway in Europe under European conditions and requirements.

The subject will be considered in the following order :—

1. The general kind of conduit to be adopted.
2. The mechanical and electrical bases on which to construct a conduit.
3. The special apparatus necessary for a mixed conduit and trolley line.

General Kind of Conduit.—The first question to be solved in the construction of a conduit is the conductor, with which is intimately connected the manner of making contact. With the limited clearances in a conduit, there can be no other practical method than that of employing rigid conductor-bars, to which the original Buda-Pesth conduit owes its success. Apart from that, it had no special feature which was of enough importance to make it a success where others had failed. The conservatism, not unnatural under the circumstances, shown in the construction of this road may be judged by the fact that 300 volts distribution was adopted, while now engineers have no hesitation in using 550 volts under similar conditions.

The next question is whether the conduit shall be of side-slot or centre-slot construction. If the engineer has his choice, he will undoubtedly adopt the centre-slot. In some of the cities on the Continent there is an objection on the part of the municipal authorities to the centre-slot. Therefore in Buda-Pesth, Berlin, and Brussels the side-slot only is allowed, while in Lyons, Nice, and Bordeaux the centre-slot has been . or is being adopted. There are some short stretches of centre-slot in Paris, but the reasons for these were exceptional, and in general this city may be classed in the first category also, 95 per cent. of the conduit mileage having the side-slot. Of the 45 miles of conduit electric railway constructed in four European cities and one American city, with which the author has been associated as chief engineer, $30\frac{1}{2}$ miles have the centre-slot, and the remaining $14\frac{1}{2}$ miles have the side-slot. His original opinion of the greater advantages of the centre-slot has been somewhat modified by experience, but he still believes that from a working point of view the centre-slot is better.

The inherent difficulty with the side-slot is the switch at the junction of two slots. Figs. 1 and 2, Plate 53, show the two cases. With the centre-slot a comparatively light movable tongue can be hung or pivoted to the fixed tongue, being used simply to guide the plough. With the side-slot the tongue is much stiffer and heavier, because in one position it must guide the wheels of the car and also support them; that is, the entire tongue is movable, and its upper surface from point to heel must be level with the wheel rail. At its point it should have a certain thickness to give mechanical strength. This should be not less than $\frac{1}{2}$ inch, and, added to the 1 inch minimum width of slot, gives an opening of $1\frac{1}{2}$ inches, which is gradually reduced to 1 inch in a length of about 3 feet. With the centre-slot construction the normal slot width of say $\frac{3}{4}$ inch is increased in a length of about 8 inches, and the maximum increase is about $\frac{1}{4}$ inch. Another objection to the side-slot is that the flanges of the wheels throw water and mud into the conduit and upon the plough. Another is that the slot-rail being also a wheel-rail should have a vertical web, which diminishes the distance across

from rail to rail on the line of their base-level, thus limiting the plough construction, and also making the conductor-bars invisible from above, which renders the finding of faults more difficult. The principal trouble with the side-slot is that connected with the switch; it can be avoided by a special construction, which will be explained later (page 383). The advantages of the side-slot are that the additional band of iron in the street, introduced by the centre-slot rails, is avoided, and that the maintenance of the paving is thereby simplified, since every contact of a rail with the paving is a source of weakness in the life of the paving.

Mechanical and Electrical Details in the Construction of a Conduit.—When the broad question of the kind of conductors and the position of a conduit has been settled, the design in detail of the conduit can be undertaken. The first matter is insulators and their mode of fastening. In the present state of the art there can be no question about adopting a porcelain insulator, or at least a material which has the same general characteristics. The first line equipped in New York City used a built-up insulator, consisting of a bolt covered with an insulating compound; it failed, and the insulator which had proved so successful at Washington was then adopted. In Brussels the insulator used is a bolt surrounded with a rubber compound, which is subjected to a severe piercing test with a Rumkorff coil before being accepted. These insulators have been fairly successful; but they are expensive, and they may also deteriorate by exposure to the atmosphere. The iron-clad porcelain insulator is strong, durable, and cheap; there can be no hesitation about its use. The insulators should be vertical, so that they may not offer the chance for accumulation of dirt, which can easily happen with one placed horizontally. The first Buda-Pesth road had this fault, but it was rectified in the later construction in that city.

Assuming a vertical iron-clad porcelain insulator, the method of attaching it to the conduit becomes important, because the depth of the tube is somewhat dependent upon this. For the sake of simplicity it should be fastened to the metallic structure of the conduit, with

the further advantage of keeping the conductor-bars at the same depth below the wheel rails, except in a centre-slot conduit, where the construction of the yokes or successive lengths of conduit does not permit of their carrying the wheel rails. The extreme positions of the insulator are, first, with the upper surface of the insulator as near the street surface as it can be for mechanical protection, or say 2 inches; secondly, with the upper surface of the cast-iron insulator-cover bolted directly to the bottom flange of the slot-rail. Fig. 3, Plate 53, is an example of the former. Here the insulator could have been reduced in height so as to carry the conductor-bars higher; but this height is limited by the safe insulation-distance required between the bars and the slot-rail. Assuming this distance $3\frac{1}{2}$ inches —so as to allow the depth of yoke-seat to diminish it by about $1\frac{1}{2}$ inches, leaving 2 inches of air-gap—the top of the conductor-bars will be $10\frac{1}{2}$ inches below the top of a slot-rail 7 inches high. Fig. 4 is an example of the second method with the same slot-rail. The insulator has been reduced in vertical height to the safe limit of mechanical strength. The corresponding distance to top of conductor bar is 14 inches, or a gain of $3\frac{1}{2}$ inches in the conduit depth for the first method of construction.

If the insulators are carried close to the street level, they must be protected by metallic covers, which in Europe are considered objectionable, and in some places are absolutely forbidden by the authorities, as in Paris. Therefore the second method is the only one that can be used in such places. Although the insulators still have to be protected by metallic covers in the second method, these are paved over, so that the street surface is in no way altered in appearance by their use.

The limiting depth of conduit is often a vitally important matter for the crossing of immovable sub-surface obstructions. As just explained, the level of the conductor-bar is arrived at by adding the depth of yoke-seat and the air-gap to the height of the slot-rail. It is possible that the height so arrived at will not give the necessary distance for an insulator hung vertically and for its mechanical protection. The insulator then determines the height at which the conductor-bar must be carried. When this height is determined,

the height of bar itself, with the necessary clearance to the bottom
of the tube, is added, which gives the conduit depth.　The clearance
should be from 9 to 10 inches, in order to allow considerable room
for accumulation of water and dirt which might otherwise endanger
the working of the road.　For short distances however the clearance
can be reduced to 4 inches, where it is necessary that the conduit
should be reduced in depth from any cause.　This clearance the
author has used in a number of instances, and knows from experience
that it is practically acceptable ; but all such short lengths of
conduit need cleaning often.

Fig. 6, Plate 54, is an example of a shallow conduit, which was
designed for use on the Pont de l'Alma in Paris.　The depth to top of
conductor-bars is 8 inches, the height of bars 4 inches, the clearance
4 inches, and the thickness of the cast-iron continuous tube $1\frac{3}{16}$ inch,
or a total height of about 17 inches.　Fig. 7 shows a section of the
insulator for the same construction ; and the plan, Fig. 8, gives the
appearance of the insulator cover in the street.　This construction,
while entirely practicable, had the inconvenience in that particular
instance of carrying the conductor-bars at a different height from
what they had in the regular construction of the conduit.　Special
means would have been necessary to raise the plough on this stretch
of the road.　A careful examination showed that the construction
given in Fig. 5, Plate 53, was practicable by slightly cutting the
masonry arches, which was accordingly done.　Here the conduit
construction has a total depth of about 22 inches, with 6-inch slot-
rails, and insulators bolted to their bottom flanges.　The conduit
shown is in actual operation, and it can be safely recommended for
special cases where the depth available is restricted.　Fig. 9, Plate 55,
is a view of the conduit during construction.　One side of the cast-iron
tubes is here shown specially curved to fit the centre longitudinal
arch, so as to avoid excessive cutting of the masonry.　Fig. 10 is a
view of another special construction over the steel railway bridge of
the new line from the Gare St. Lazare to the Invalides.　Here the
conduit rests directly on the steel beams of the bridge, and spans
from one to another of them ; it therefore had to be in the form of
a bridge itself, and a built-up beam construction was adopted.

Where the regular yoke construction is used, the yokes project from 6 to 8 inches below the tube depth, which is normally from 24 inches to 28 inches; the additional depth depends upon the method of suspending the insulator, as already explained, and gives, roughly speaking, extreme depths of metallic structures between the limits of 17 inches, Fig. 6, Plate 54, and 36 inches. A careful examination should be made of a proposed route, to see if the sub-surface constructions permit of building a safe practicable conduit. With this broad question settled in the affirmative, there is no good reason why the expense and annoyance, due to the removal and lowering of many sub-surface obstructions, should not be avoided by taking advantage of the possibility of varying the depth required for the conduit. It becomes a grave matter only where the question may involve the complications due to changing the carrying height of the conductor-bars, in order to get the minimum depth of conduit. It might be suggested that the conductor-bars could be carried at this minimum height throughout the entire length of conduit; but an examination of Fig. 6 will show that it is possible only with a slot-rail of about 4 inches height, which again is practicable only with asphalt paving.

The switches are responsible in practice for most of the interruptions in service. A misplaced switch has the result of guiding the car in one direction and the plough in another. The plough can become twisted in the conduit in a variety of ways, with the too sure result of interrupting the traffic for a time, which, in the author's experience, may vary from fifteen minutes to two hours. This bare statement is sufficient to demonstrate the necessity of so designing the switches, as to reduce to the strictest minimum the possibility of such accidents.

There are two distinct cases to be considered. The first is where the track is alone switched, the slot being continuous. Fig. 11, Plate 55, is a photographic view of such a switch for a centre-slot conduit. Fig. 12, Plate 56, is a sectional view of a counter-weight mechanism which can be adjusted to close the switches automatically, so that the track should be always open for the passage of the cars using the conduit track. Fig. 13 is a section of the same mechanism for a side-slot conduit. The above precaution should always be taken,

but it may fail. When failure happens, it is usually due to something solid having fallen into the switch, and in consequence the tongues fail to return to their normal position. In the centre-slot conduit, the danger of an accident can be avoided if the ploughs are hung on slides, which permit their travelling completely across the car. If the ends of these slides are left free of all obstruction from the truck or otherwise, the plough will drop off when the car has reached a certain distance on the wrong track. But the motor-man generally perceives his error before that occurs, and simply stops and reverses the car, with the result of no interruption worthy of mention. Even in the worst case of losing the plough the car is simply " dead," and can be pushed on by the succeeding one. A trap should be placed conveniently at every such switch, so that the plough can be taken out without loss of time. If the accidents are only of this nature, they are not worthy of any serious attention. But in the ordinary side-slot conduit, this result cannot be attained. There the tongue in one position covers the slot. In the event of this false position of the switch, an accident will happen which almost surely must result in a serious interruption of the car-service. To avoid such a difficulty, the author suggests that, before the switches are reached, the slot should be deflected to the central position. Plate 57 shows how it may be accomplished.

In the second case, with a slot-switch, the slot-tongue is a necessity. The author recommends for the side-slot conduit the same deflection of the slot to the central position. This serves the purpose of being able to avoid the slot-switch of the side-slot, the constructional difficulties of which have already been enlarged upon. The danger of an accident with this switch is limited to the case where the point of the slot-tongue is directly in the slot; a " head-on " collision can then take place. But if the tongue is not thrown on the same direction as the track-tongues, the same slight interruption may happen as already explained, providing of course that the same system of plough slides is in use. Fig. 16, Plate 58, shows the case of a side-slot conduit deflected to the centre of the track at a slot-switch. Here there are no mechanical or

electrical difficulties, as demonstrated by the results of actual working in Paris. Fig. 17 is a view of mechanism for working a slot-switch. With one movement of the handle the three tongues are thrown in unison. For a dense traffic, it is advisable to put a switchman at the slot-switch points, in order to reduce to a minimum the danger of accidents and of interruptions to the service. The author feels confident that the accidents at switching points will be devoid of importance if the construction above indicated is followed.

Special Considerations for a " Mixed " Line.—The first question to be decided for a line partly conduit and partly overhead is whether the plough shall be carried continually on the car, or removed and replaced at each junction of the two systems. The latter is the simpler method. A roomy man-hole admitting a man to do this work is all that is needed ; but it needs no argument to prove that it is an undesirable and expensive method to adopt. Preference is therefore given to a method whereby the plough is always carried on the car, as the trolley is ; for which purpose the plough must be raised or lowered at the junctions of the two systems. The most natural and the neatest solution is to raise the plough through the slot, with no special arrangement in the slot. This has been successfully done in Berlin and Brussels. In Berlin the plough is equipped with a wheel at its lower extremity, which runs up an inclined plane ; and the contact-shoes working on horizontal axes pass through the slot by being depressed into a vertical position. The wheel then runs in the groove of the wheel rail, and is raised clear of the track by turning a crank. At the same time the conductor loosens the bow sliding-trolley, and the operation is complete. The entire change can be made without stopping the car. A more perfect contrivance to accomplish this purpose could hardly be devised. In Brussels the plough is raised entirely by the motor-man, the inclined plane being discarded. A wheel-trolley is used, so that a stop of the car is necessary in order to catch the trolley wire.

Both of these devices involve the use of what the French call " clapets," which in English may be called " flappers." They are

hung on a fixed horizontal axis, around which is a coil spring; one end of the spring is fastened to the fixed axis and the other to the flapper, so that the springs make the flappers press against the conductor-bars. The contact may be made either on the vertical or on the upper face of the bars, according to the way the road is designed. The flappers are not thick, and the whole construction of the plough is closely cramped, for enabling it to pass through the 1¼-inch slot. The plough of this form is withdrawn easily; but it has to be specially weighted in order to make it descend, for it has only its own weight wherewith to overcome the tension of the flapper springs, and make them take the vertical position necessary for passing through the slot.

If no other complications were involved, there could be no good reason for not adopting one of the above designs of plough for a side-slot conduit with 1¼-inch slot: for a centre-slot, with ¾-inch width, their use is out of the question. But the plough is one of the most difficult problems connected with the conduit traction. The successful application of two bare conductors in an open-slot conduit is not as serious a matter as to take the current from these bars through the slot to the car-motor. A plough must be strong enough mechanically to resist the shocks and wear and tear of ordinary usage, while not so strong but that it will yield before injuring the conductor-bars in case of an accident. At the same time it must be electrically efficient under the most difficult conditions imaginable : bare collectors of current are connected to leads, which must be covered with insulation and mechanically protected by metallic wearing-plates, and the total width must not exceed ½ inch, with a ¾-inch slot, this being the ordinary condition with a centre-slot conduit. The plough is often drenched with water and covered with slime and mud, which run down its sides from the open slot. The conditions are certainly severe for an apparatus having to carry successfully a 500-volt current. No form of plough yet designed is so perfect that any of its advantages may be sacrificed to gain other features, which can by any means be dispensed with. In the author's opinion the design of the plough should have the first consideration, and the conduit and special apparatus

connected with a road should be built "around" the plough as a nucleus.

The flapper form of plough is weak mechanically. The friction of the uneven joints in the conductor-bars, and the shocks due thereto, tend to twist the flappers about their horizontal axes. At the points where the bars are interrupted, as at slot-switches or at crossings, the shocks of this nature are so considerable that in actual practice the flappers are often wrenched off at these places. When released from their fixed position against the conductor-bars the flappers take a position that is variable, depending upon the tension of the coil springs, which naturally cannot always be the same. A warped-surface extension-piece has to be fastened to the ends of the conductor-bars, to guide the flappers to their normal position against the bars. These pieces give considerable trouble, and their use should be avoided, if possible. This form of construction does not permit the use of a fuse to connect the contact-shoe with its lead; consequently a short-circuit in the body of the plough, not being protected by the car-fuses, would short-circuit the line, and thereby stop the traffic until the faulty plough could be discovered and raised out of the slot. The author believes it to be indisputable that other forms of plough are much more efficient; but none of them have the advantage of being able to be withdrawn from the conduit, or lowered into it, without a special trap at a fixed point. Nevertheless, if the above reasoning is sound, one of the other kinds of plough should be adopted, and it could be a question only of choosing the best existing and improving it.

In the light of present experience the best plough is one having soft cast-iron shoes, pressed lightly against the vertical faces of the conductor-bars by semi-elliptic springs placed horizontally. The shoes should preferably be carried by horizontal links, which take all the shocks they may be subjected to, leaving the springs free to do the work only of pressing the shoes outwardly. In this way the risk of deforming the springs is avoided. The links should be constructed so as to limit the outward movement of the shoes. The conductor-bars at switches and crossings are simply curved slightly outwards. The shoes are connected to the leads by copper fuses. This construction of plough is simple; in actual results it has proved

itself to be efficient. It certainly is an improvement upon the "flapper" plan.

The simplest form of trap would be one in which the lids required to be lifted before the arrival of the car, and to be put back in place after its departure. This however would rightly be considered a crude and laborious operation. Plate 59 shows a form of trap which is moved after the car has reached its position. One throw of the lever opens the trap, which is so counterweighted that the effort necessary for opening is almost inappreciable. This trap has given excellent results in France, where forty of them are in operation. Where the flapper form of plough is used, it is lifted by means of an apparatus similar to a brake-staff, which is placed on the platforms of the cars. The plough is connected to the staff by means of cables, which are guided by sheaves conveniently placed. On account of the width of slot in the side-slot conduit, necessitated by the fact that it must be wide enough for the wheel flanges, the flapper form of plough has been adopted for this construction of conduit only. The ploughs are raised in guides attached to the side frames of the truck. In Brussels and Berlin the ploughs are not mounted on slides permitting a lateral motion across the car. As the two side-slots of a double track are situated next to the inner rails, it is necessary to carry two ploughs, with a raising and lowering mechanism for each. If the requirements of the road demand cross-over switches from one track to another, a third conduit is necessary for a short distance at such places. The deviation of the slot to the centre with the necessary plough-carrier entirely obviates the difficulty of two ploughs and of a third conduit.

The use of the slides seems to the author to be a valuable feature of conduit electric railroads, for the various reasons that have been already given. Therefore the following explanation of a raising and lowering device for the plough, which will permit this sliding feature, is given in detail. Plate 60 gives three views of such an apparatus. A are the side bars, B the top bar of the truck, and C the brake-rods, which must be placed outside the wheels as here shown. D is the plough shown in position

on the side-slot conduit; it slides from this position to that of (1) for the centre-slot, or of (2) for the side-slot of the other track when crossing from the inner conduit on one track to the inner conduit on the other track. The bars E are the slideways. The bars F prevent the plough from rising or tilting in the conduit, except in the central position (1), where the casting G, held in position by the lock H, performs the same function. The slidebars E and F are held in position by the steel castings I. The projecting central piece J, braced as shown, holds the plough in its raised position. The whole apparatus is supported by the channel beams K, which are bolted to the side-bars of the truck. In this way the vertical variation in height is limited to the small movement in the axle-box springs of the truck. The plough is raised in the following manner. The fixed screw L is turned by means of a removable crank placed at M. The block N travels from one end of the screw to the other; it is shown in its position when the plough is raised; it carries the two rollers O, over which run heavy-link chains. The latter are fixed stationary at one end P, and at the other end are attached to the casting G, which is thus raised by an amount equal to twice the travel of the block N. The latch R automatically locks the block in place when it reaches the outer end of its travel. This prevents the shaking of the truck from lowering the plough when it is in its raised position for the overhead-trolley section of the road. The box S covers the double-pole switch, which puts the car-leads in circuit either with the overhead or with the conduit line. This is done automatically with the raising or lowering of the plough by means of the rod T, which is moved by the block N when near the end of its travel in each direction. Fig. 21, Plate 61, is a photographic view of a car equipped with this plough apparatus, showing that externally the whole apparatus is nearly invisible. Figs. 22 and 23, Plate 62, are side views of the truck alone so equipped, and Fig. 24 is an end view of the same truck. The author is indebted to Mr. E. W. Mix, the Chief Engineer of the Société des Établissements Postel-Vinay of Paris, for his invaluable assistance in the design and manufacture of the apparatus above described. That it has been successful is largely due to his efforts.

It is a good plan to shape the piece M, Plate 60, so that it will fit only such a controller-handle as can be removed from the controller on the " off " position only ; so that if the handle is used to raise or lower the plough, there can be no movement of the controller until the operation is finished.   Generally there are two traps at the junctions of the two systems, one for each track.   Although the conductor of the car can work the trap, it is preferable to have a man specially stationed for the purpose, if the car traffic is at all frequent.   In practice the operation is as follows : a mark on the track gives the motor-man the exact position to stop at ; and when the car has stopped, with the plough over or under the trap, he gives his controller-handle to the trap-man, who opens the trap, and lowers or raises the plough, closes the trap, and returns the handle to the motor-man.   At the same time the conductor lowers or raises the trolley from or to the trolley wire.   The whole operation takes on the average ten seconds when the men become accustomed to it.   If these junctions coincide with regular stopping-places to load or discharge passengers, the loss of time due to this operation is inappreciable.   The only arcing at the conductor-bars and at the automatic switch S, Plate 60, is that due to the lighting circuit.   This is too small to have any injurious effect upon the plough-shoes ; and the construction of the switch with a quick break is such as to remove any danger there also.   If electric heaters should be used, requiring rather large currents, it might be necessary to cut them out of circuit during the operation.   The car wiring for the mixed system is only slightly more complicated than for one system alone.   The conduit circuit being completely insulated, the ground-wire must be removed from the controller.   Two wires are run from the controller to two points on the double-pole switch S, Plate 60.   These two points are thrown in by the switch, with one pair of points connected to the two plough-leads, or with another pair connected to the trolley pole and the earth.

In the electrical apparatus the only special precautions to take in using a conduit are, first, to have the field coils insulated for 500 volts.   With an overhead line the difference of potential between the field and the carcass of the motor is that due to the drop in the

fields.   But with a conduit it can happen that one pole of the conduit circuit is grounded, and that the fields are directly connected with the other pole.   This would give 500 volts difference of potential between the carcass of the motor and the field winding. All standard motors should stand this condition, but it should not be omitted to be specified by the buyer.   Second, when electric brakes are used, special insulating precautions are vitally necessary for the brake coils.   A grounded conductor-bar can subject them to 500 volts pressure during the entire time the car is on the conduit section.   Not only has the annoyance to be considered of burning up the coils, but also that of short-circuiting the line.   An interruption of this kind is overcome by lowering the line voltage by means of a rheostat at the station, so that an increased current, the amount of which is controllable at the switchboard, may be sent through the fault.   This excessive current will burn the plough fuses, thereby clearing the line at the expense of leaving the faulty car " dead," to be hauled in by the succeeding car.

With a combined trolley and conduit line the conduit section should have a separate circuit.   It may be possible to work it successfully with a grounded return, but few engineers would care to propose doing so.   It is much better to increase the effective factor of safety by having both sides of the circuit insulated.   If the conduit section or sections are reasonably close to the power-station, this may be done with a separate dynamo situated there for the conduit circuit, or by means of a motor-generator.   If the cost of the leads to the conductor rails from the station is excessive, the motor-generator set may be stationed near the conduit section, and supplied with current from the overhead circuit.   The proper solution may be one of many different plans, depending upon the local circumstances governing a specific instance.   As a result of actual tests it has been found that conductor-bars of mild steel, electrically connected by two bonds at each joint, have a carrying capacity of about one-eleventh of copper bars of the same cross section.   The mild-steel bars can be largely increased in electrical carrying capacity by attaching to them bare copper cables for this purpose.   It can be readily seen what an economy this method affords over that of

laying insulated cables in ducts. Fig. 20, Plate 61, is a view of the mode of laying these feeder cables in Paris. The cables here shown have a cross section of 250 square millimètres or about 500,000 circular mils. The cables are electrically connected to the bars at such short distances apart as to avoid electrolytic action between the two metals.

Cost of Conduits.—This question must be treated in a general way, because local circumstances constitute such a large factor in the determination of cost that no other way is possible. Some notes as to details of cost will be found in Appendices I and II (pages 393–6). The side-slot conduit can be built for about £500 less per mile of single track than the centre-slot. In the special work there is also an economy in the side-slot as ordinarily built, because there are fewer frogs with three rails than with four. But if the slot is deflected to the centre, as has already been recommended, the economy cannot be realised; on the contrary, the cost will be somewhat greater, owing to the cast-steel deflecting pieces and the bent slot-rails. It is generally stated that a conduit road costs twice as much as an overhead-trolley road. Such a statement may be misleading, owing to the fact that an overhead-trolley road may vary greatly in its cost, depending upon pavement requirements, nature of the overhead construction adopted, and many other local conditions, such as the regulations for the return current by the rails. But the construction of the conduit part of a road is quite independent of these factors: that is, if an overhead-trolley road would cost £5,000 per mile of single track, it is quite probable that the same road with the conduit construction would cost £11,000 for the same length, so that the conduit properly speaking would cost £6,000 in excess of an overhead-trolley road. If the first cost of the overhead-trolley line should be £10,000 per mile of single track, there is no reason why the use of a conduit on such a line should then double the cost; roughly speaking, the cost of a conduit would be £16,000. To arrive at an approximate comparison of the cost of the two constructions, it is fair to assume that the cost of paving and of the wheel-rails is the same in both cases. For the

conduit there should be added per mile of single track approximately the following material and labour :—105 tons of slot-rail, 40 tons of conductor-rails, 210 tons of cast-iron, £120 excess for bolts etc., £35 for porcelain insulators, 1,400 cubic yards excess excavation, 1,200 cubic yards excess concrete, £600 excess labour for track-laying, and £400 for sewer connections. Crossings, turn-outs, and special track work in general, cost 200 per cent. more on an average for the conduit than for ordinary track. A cost which is wholly indeterminate is that of removing sub-surface obstructions. This, as has been explained, can often be reduced by varying the depth of conduit to suit special circumstances.

The items above enumerated will alone amount to between £5,500 and £6,000. Deducting the cost of an average overhead construction, it can roughly be said that a conduit road will cost from £5,000 to £5,500 more per mile of single track than a trolley road under the same conditions : to which should be added the increased cost of special track work and the removal of underground obstacles. Under ordinary conditions the difference in cost will vary between the limits of £7,000 and £9,000 per mile of single track.

The Paper is illustrated by 10 Plates, Nos. 53–62, and is accompanied by two Appendices.

APPENDIX I.

Details of Cost in United States.—The following Table gives the actual cost per single-track mile of the conduit roads constructed by the author in 1895–6 for the Metropolitan Railway of Washington, D.C.

Cost of Metropolitan Railway, Washington, D.C.

Straight track . . 101,660 feet.
Curved track . . 9,190 ,,

110,850 feet—say 21 miles of single track.

Rails and splice bars per ton:—	£	s.	d.	
Wheel-rail	5	15	0	per ton.
Slot-rail	6	8	6	,,
Guard-rail for curves	9	10	0	,,
Conductor-rail	8	8	0	,,
Joints complete		4	10	each

PER MILE OF SINGLE TRACK.	£	s.	d.
Rails and splice bars	1,858	6	8
Cast-iron (yokes, insulator frames, covers, etc.), 215·5 tons @ £5 15s. 7d.	1,245	8	2½
Bolts, tie-bars, clips, etc.	312	10	0
Bonds for conductor-rails	97	18	4
Track laying—hauling and all labour	589	3	4
Temporary track	33	6	8
Excavation of all kinds except for cable ducts, 2,507 cubic yards @ 3s. 10¾d.	488	6	10
Sewer pipes laid, and brickwork for duct man-holes . . .	99	7	6
Cable ducts:—			
10,616 feet 12-way duct @ 4s. 9½d. ⎫			
41 ,, 8 ,, ,, 3s. 6½d. ⎬ £1,894 3s. 9d. .	233	1	1
21,354 ,, 4 ,, ,, 2s. 2¼d. ⎪			
113 ,, 2 ,, ,, 1s. 5d. ⎭			
Excavation for cable ducts, 9,207 cubic yards @ 3s. 4d. = £1,531 10s.	73	1	5½
Concrete, first grade, for conduit (1 barrel Portland cement to 12 cubic feet sand and 22½ cubic feet broken stone) 765 cubic yards per mile @ £1 9s. 2d.	1,115	12	6
Carried forward	6,146	2	7

	£	s.	d.
Brought forward	6,146	2	7

Concrete, second grade, for paving base, etc. (1 barrel
Cumberland cement to 10 cubic feet sand and 20 cubic feet
broken stone) 514 cubic yards per mile @ 18s. 1d. . . 464 14 10

Stone paving, using old setts,

	£	s.	d.
42,126 square yards @ 3s. 3d.	6,845	9	6

Asphalt pavement,

91,716 square yards @ 6s. 0½d.	27,705	17	6
	34,551 7 0	1,645	6 0

Special track work and curves. 783 6 8
Extra bills of street contractor. 239 11 8
Removal of sub-surface obstructions 666 13 4

Total cost per mile of single track . . £9,945 15 1

The metallic structure cost less at that date than it would now. The temporary track is a low item, because the authorities permitted a flat strap-rail to be laid on the pavement (mostly asphalt) by means of flat tie-bars with special seats at their extremities. It should be stated that Washington is an exceptionally favourable city for the construction of conduit roads, because the streets are wide and with little traffic upon them, and the supervision is by the thoroughly trained engineers of the United States Army.

A pamphlet received by the author, containing some diary notes kept by Mr. William C. Gotshall, Engineer in charge of construction of the Second Avenue Railroad of New York, concludes with the following estimate of the cost of this road per mile of single track. The estimate is not Mr. Gotshall's, but is the work of the compiler of the pamphlet :—

Total Cost per Mile of Single-Track Open-Conduit, Second Avenue Railroad, compiled from diary of W. C. Gotshall.

	£	s.	d.
Labour, digging trough, removing old track, repairing concrete, removing excess dirt, hauling all track work, £1 10s. 11½d. per linear foot	8,173	0	0
Insulators 5s. 8d. each	199	9	7
Iron work, excluding yokes, 7s. 4d. per linear foot . .	1,375	7	0
Cost of cast-iron yokes, 224·7 tons at £5 4s. . . .	1,168	8	10
Carried forward	10,916	5	5

		£	s.	d.
Brought forward		10,916	5	5
Concrete, ⅔ cubic yard per linear foot, 8s. 2d. per yard.	.	808	10	0
Haulage on yokes and iron work	.	117	1	8
Total, exclusive of paving and feeder duct . . .	.	11,841	17	1

In comparing this cost with that of the Washington conduit, it should be borne in mind that the items of cost for special track work, feeder ducts, paving, bonds, sewer connections, and temporary track, are not included in this estimate, while they are in the Washington costs. The cost of concrete is here put down at 8s. 2d. per cubic yard, which is evidently an error of compilation ; other information in the pamphlet seems to prove that it should be from 2½ to 3 times this amount.

APPENDIX II.

Estimated Cost in England.—The author ventures to submit the following estimate of cost per single-track mile in England at ruling prices of material and under fair average conditions. The construction here contemplated is a centre-slot conduit, with yokes spaced 3 feet 6 inches centre to centre, and of the same weight and general dimensions as the yokes used on the Paris lines. Yokes need not be inordinately heavy, but they should by all means be close enough together to preserve the slot width, which is a much more important matter for an electric conduit than for a cable road.

Estimated Cost of Single-Track Mile of Conduit Electric Tramway in England for average conditions (December, 1900).

	£	s.	d.	£	s.	d.
Wheel-rails, 90 lbs. per yard, 141 tons per mile at £7	987	0	0			
Joints, 0·67 ton at £8	5	8	0			
Slot-rails, 66 lbs. per yard, 105 tons at £8 .	840	0	0			
Conductor-rails, 28 lbs. per yard, 44 tons at £8	352	0	0			
				2,184	8	0
Haulage, 290·67 tons at 4s.				58	2	0
Bolts, washers, keys, etc., 4·16 tons at £18 .	74	18	0			
Tie-bars, 13·5 tons at £15	202	10	0			
				277	8	0
Carried forward				2,519	18	0

	£	s.	d.
Brought forward	2,519	18	0
Insulators complete with clip, 755 at 6s. 2d.	232	16	0
Cast-iron yokes and insulator-pit covers :—Yokes, 210 lbs. each, spaced 3 feet 6 inches centre to centre, 210 lbs. × 1510 = 317,100 lbs. = 141·5 tons. Insulator-pit covers, 117 lbs. each. 755 × 117 = 88,335 lbs. = 39 tons. Total 180·5 tons at £10 .	1,805	0	0
Haulage, 181·5 tons at 4s.	36	6	0
Bonds	110	0	0
Concrete for tube (1 cement, 2½ sand, 5 broken stone) 0·2 cubic yard per linear foot × 5,280 feet = 1056 cubic yards at £1 8s.	1,478	8	0
Concrete for paving (1 cement, 3 sand, 6 broken stone) 0·1 cubic yard per linear foot × 5,280 feet = 528 cubic yards at £1 4s. .	633	12	0
Wood paving, 6,373 square yards at 11s.	3,505	3	0
Excavation, 2,950 cubic yards at 5s.	737	10	0
Sewer connections, and manholes for same	400	0	0
Plate laying, including average amount of special track work, 5,280 feet at 3s.	792	0	0
Temporary track (1 track laid and repaved on side of street with turn-outs) at £1,350 per mile of street (divided into two tracks for double-track construction)	675	0	0
Special track work of cast-steel construction with hardened centres	1,128	0	0
Obstructions (necessarily indefinite) say	1,000	0	0
Feeder ducts	800	0	0
Extras and contingencies	630	0	0
Total estimated cost per mile of single track	£16,483	13	0

Certain costs, notably those for temporary track, feeder ducts, obstructions, special track work and curves, must be largely conjectural; but for average conditions and for this class of construction the author believes the above figures will be reasonably safe, except for the item of sub-surface obstructions, which may be small or inordinately large, depending upon local circumstances.

In closing, the author wishes to emphasise the point that the electric transmission for a conduit road being wholly insulated can be calculated for the most economical drop of potential, which is not the case for an overhead line with rail return. Considerable saving, either in copper or boosters or both, can thereby be effected, which should be put to the credit of the conduit in any estimate of its cost.

Discussion.

The PRESIDENT said the author had written an interesting Paper on a subject of very great importance to the country at the present time.   The application on a large scale of electric traction in England had only just been commenced, and the Paper therefore came at an opportune time when English engineers were most anxious to find out, as far as possible, all the defects in the systems which had been put to work elsewhere.   He hoped the Paper would be thoroughly discussed.   He was sure the members would accord to the author a very hearty vote of thanks for the trouble he had taken in bringing the matter before the Institution.

Mr. JOHN S. RAWORTH said that two principal features had struck him in connection with the Paper.   One was that the author was a man who knew what he was talking about ; he had met with certain difficulties, and he appeared to have been very successful in overcoming them.   The second point that struck him about the Paper was that all the illustrations save one were to be found in the City of Paris.   The City of Paris was, from many points of view, a civilised city, but from the point of view of its roads it was not a civilised city.   If the author could have brought one example from London of a conduit system, it would have been more convincing, if that conduit had been permitted to remain, than fifty examples from Paris.   Within the last six months, in going between the Grand Hotel and the Gare de Lyons, he had seen a hole in the road into which a four-lb. loaf could be put.   Further, he could say without any hesitation whatever that the worst part of the whole of the journey from Charing Cross to the Grand Hotel in Paris was the piece traversed between the Gare de Nord and the Grand Hotel.   If the London and North Western Railway were put down in the Rue Lafayette, standing 5 or 6 inches above the surface of the road, and a crossing were placed at every 100 yards, it would be very much more comfortable for the passengers in cabs and carriages than the present arrangement.

(Mr. John S. Raworth.)

Having premised his remarks in that manner, he wished to consider the various sections and details which the author had placed before them.   Most of the members were aware that the London County Council were proposing to put down a conduit system in London, which he believed would be the first example of its kind in England.   From his youth upwards he had observed that there existed a violent antagonism to tramways.   That antagonism had been raised on the part of everybody who owned a carriage or rode in a carriage.   Tramway construction in this country had been carried forward and brought to its present state of efficiency principally by the power and ability of companies, with a view to overcoming the objections of carriage-owners and users to the rails in the road.   If tramway people could see their way to slinging the rails in the air, hanging the tramcars from them, and having no metal whatever in the road, the owners and users of carriages would be, he believed, better pleased than they now were.   But the rails put into the road were very narrow; the tread of the wheel was perhaps $1\frac{1}{2}$ or $1\frac{3}{4}$ inches, and the total width of iron which the horse had to tread upon was not more than $2\frac{1}{2}$ inches.   If one looked at the Plates annexed to the Paper, which were not any worse than the drawings the County Council were at present considering, it would be found there was a total width of 6 inches of metal.   That was almost as bad as making it a foot.   It was very nearly, if not quite the width of the horse's hoof, and therefore quite sufficient to destroy the horse's foothold.

Another matter which the author had explained was that it was possible to put down a conduit system with a slot of $\frac{3}{4}$-inch width. He was very glad to hear that, because he had read, as no doubt nearly all the members had, the reports of very enterprising town councillors who had gone all over Europe in quest of systems of electrical tramways with conduits, and who had, as usual, not been satisfied until they had gone as far as Buda-Pesth.   The reports presented by the councillors to the Mayor, Aldermen, and Corporation had been very interesting and glowing, but they never mentioned the fact that in Buda-Pesth the slot in the road was big enough for a cat to get into.   In Brussels he had tested the slot,

and it measured on the average from $1\frac{1}{4}$ to $1\frac{3}{8}$ inch, but there were places where he was perfectly sure a child could fall in up to its knees. Such big slots would not be made in England, as no authority would by any possibility accept them. He was very glad to hear it was possible to make a practical working slot with an aperture of no more than $\frac{3}{4}$ inch. No company would dare to face the ignominy of putting 6 inches of iron in the middle of the road, and if the County Council intended to cut up the streets as nobody but a municipality dare cut them up, it would have to take into serious consideration whether the exposed surface of iron could not be very considerably reduced. The author had given good advice to the mechanical engineers. He had said to them, "If you employ accumulators, take them on hire." If he had been reading the Paper before the Institution of Electrical engineers he would have said, "Do not let your accumulators on hire to those people; they will ruin them in the first six months; sell them outright, and get the money in your pockets."

Mr. S. Z. DE FERRANTI considered the value of the Paper was shown by what the author had put before the members in the shape of the combination of the overhead and the underground systems of electric traction. There had been repeated disputes before all the local authorities who had considered electrical tramways in large towns as to which was the best system to adopt—the overhead or the underground. The author had shown that two systems were available for most cities. Anyone who had carefully considered the problem must agree that the overhead system in a large city became an intolerable nuisance, and yet it was known it would be commercially impossible for electric tramways to exist if the underground system had to be pushed out into the sub-districts surrounding a large town. The great value of what was shown in the Paper, therefore, was that the author had plainly put before the members what could be done by a combined conduit and overhead system. Most of the members had heard a good deal lately, due especially to the unfortunate and terrible accident which had occurred in Liverpool, about the question of the overhead wires and

(Mr. S. Z. de Ferranti.)

trolley system found in some large cities. Another great city in England, Manchester, was going to do the same thing and run the same risks. As he had said before, in English towns, especially manufacturing towns in Lancashire where it was very damp, he would rather keep the electricity out of the mud by having it overhead. He thought the lesser evil was to have a properly designed conduit system in the town, and then to change to the overhead system outside the town limits in the suburbs where it became a less serious problem. The author had not touched very fully upon one point in the Paper, probably because he had said as much as he could do under the circumstances, namely, the question of obstructions found in the streets of English cities. He had reason to know, especially from his work of main laying in London some years ago, that the obstructions were simply enormous. Very little system had been adopted in the laying of underground work in London ; and he fancied the difficulties which would be found to arise from those causes would be very great indeed and lead to a considerable expense ; in fact he should say there were few places in London where obstructions could be diverted for less than £3,000 a mile. Another thing he would point out, which no doubt was very obvious, was that apparently the conduit system was a very simple one. It appeared to be a plain, simple, engineering construction, but still, like other simple things, it was one into which one might fall in a very dangerous manner. It required very careful consideration, and above all for safety it wanted a large practical experience on the part of the people designing the conduit. It was better to follow what had been done, than to try and make any great improvements and run the risk of having something very closely approximating to failure.

Mr. E. W. MONKHOUSE thought the thanks of the Institution were due to the author for bringing the subject of the combined trolley and conduit system before the Institution. He had had the benefit of seeing most of the systems to which allusion had been made in the Paper, and recognised all of them by the description. The Buda-Pesth system he believed was the oldest in the world,

having been in operation since 1881. If he was not mistaken, the form of plough used in that system was about as cheap an article as could be constructed for the purpose, costing 7s. 6d. When he was in Buda-Pesth, he spoke to the engineer-in-charge and asked him why he did not try to construct a better form of plough. The engineer replied that it was really not worth while, because it only cost 7s. 6d. to renew, and that one could therefore afford to scrap the old ones without incurring much expense. With respect to Mr. Raworth's remarks on the subject of the width of the slot (page 398), he believed the New York conduit system had a slot $\frac{3}{4}$ inch wide. The system was working over many miles, in fact the whole of the tramways in New York, with the exception of some of the cross town lines, were operated on the slot system. He thought there was no doubt that a $\frac{3}{4}$-inch slot was a practical thing. Of course it was quite impossible to have any arrangement for withdrawing the plough through the slot with such a width, for reasons clearly set out by the author, unless a trap-door system was adopted, such as he suggested. The trap-door system was at work on one of the Paris lines, which ran out to Vincennes. It was operated by means of a lever such as shown in Plate 59. He could bear out what the author said as to the time it took to change over from the trolley to the conduit system, as he had timed the operation.

The question of underground obstruction referred to by Mr. Ferranti (page 400) was, as anyone knew who had any main laying to do, a very serious matter. Whether it would cost £3,000 a mile he was not prepared to say; he thought that was perhaps a large figure. The author had not referred at all to the surface-contact system. He thought that system deserved attention and might be worked, if some satisfactory way could be found of preventing live contacts being left behind the cars. As far as he had seen, that was generally not prevented, but was brought to light by having chains hanging down at the back of the car, or by having subsidiary skates at the back, which, when they went across the live contacts, the switches not having acted properly, short-circuited the system, and either blew a fuse in the car or worked a maximum current breaker

(Mr. E. W. Monkhouse.)

which stopped the car.   The conductor then got out, went to the
nearest telephone box and telephoned to the station ; a man was
then sent to lift the lid and set things right.   He believed that was
the way it was done at Tours ; at any rate it used to be done in that
way.   He thought it was also done on a contact system which ran
out of Paris.   If a satisfactory contact-system could be devised,
there was no doubt it would be a capital thing for the centre of
large towns for the reasons that both the previous speakers had
brought forward, and also for reasons brought out by the author,
namely the cost of removing underground obstructions where the
conduit system was installed.   He thought the author had done not
only the Institution, but tramway interests in general, a great favour
in bringing forward the Paper.

Mr. M. HOLROYD SMITH said that in glancing through the Paper
he had been pleased to find that the principle he ventured to
advocate twelve years ago, namely overhead trolleys for suburban
districts and conduits for the principal streets of cities, was now
being recognised by other engineers who had a better opportunity
for putting it into effect than he had been privileged to have.   With
Mr. Raworth's permission he would fill up a blank in his remarks.
That gentleman forgot to mention the width of the Buda-Pesth slot.
He had measured it over and over again, and found that it averaged
1⅞ inch, which was very wide indeed.   It was very much too wide
to be entertained in English cities.   He would remind the Institution
that when he constructed in Blackpool the first conduit that was
ever built,* the intelligent members of the Corporation limited him
to a maximum width of $\frac{1}{2}$ inch.   Now that engineers were puzzled
and stuck fast when they had 1¼ inch to play with, they would be
able to recognise, in a way they had never recognised before, the
difficulties that beset him in the construction and working of that
line.   There was another point raised by Mr. Raworth for which
he ventured to think he gave the world the solution nearly fourteen
years ago, namely, to construct the surface of the conduit in such
a way that it would be sufficiently strong and yet present not too

* Since converted to the overhead wire system.

broad a surface for the horses' feet to tread upon.   As that little
solution seemed to have faded out of memory, he would illustrate it
in Fig. 25.   The slot through which the plough or collector had to
pass was ½ inch wide.   The surface consisted of channel steel rolled

FIG. 25.

Transverse Section of Conduit, Blackpool Electric Tramway.

in the form shown, and the spaces were filled in with blocks of wood.
The total width of steel edges was only ⅜ inch each.   So far from it
being detrimental, the horses habitually found their way on to the
cushion wood pavement ; in fact it constituted one of the earliest
examples of wood pavement laid in this country.   He was very glad
to hear the author advocate or express his preference for the centre-

2 E 2

(Mr. M. Holroyd Smith.)
slot instead of a combined slot with the rail.   He hoped that now somebody else was advocating the system corporations would begin to realise its advantages.

Mr. E. KILBURN SCOTT said he took upon himself some years ago, when many people were scoffing at the conduit, to put its claim forward on several occasions in the technical papers.   He found out that nearly all the scoffing came from people who were interested in the sale of overhead-trolley line fittings and so on.   He had followed the subject of the Paper very closely for some considerable time, and after all he thought that a good deal was to be said for the side-slot system.   When the Paris Municipal Council allowed the first conduit to be put down along the Rue de Lyons, the author adopted practically the same construction, namely, centre-slot with same size yoke, slot-rails, &c., as he had used in Washington. There was such an outcry however against the extra band of wide steel rails that the Municipal Council insisted that any further conduits should be side-slot.   The author then very ingeniously suggested the compromise of a side-slot with short lengths of centre-slot at the switches, junctions and crossing ; certainly a good way of getting out of the difficulty.   There were however, some points most distinctly in favour of a side-slot throughout—for one thing deflections to centre-slot, especially as they occurred at crossings, junctions and curves, were expensive.   Side-slots had been nearly always employed along the two interior rails, that is to say, of the four rails on a double track the side-slots were along the two middle rails, thus rendering it necessary in some cases to have two ploughs. But there was first of all no occasion why the side-slots should go down the two interior rails, they could very well be on the same side of each track as in Berlin ; and secondly, two ploughs were necessary nowadays, because it was general practice to allow the plough to traverse right across the car.   This was practically a necessity with the centre-slot or the side-slot with deflections ; because in case the car took one point and the plough another, some arrangement must be made whereby the plough could traverse along and drop off instead of jamming itself.   At the same time it was only

fair to mention that the chance of the plough going one way and the car another at a junction was much less with the side-slot, as the plough lay in the same plane and immediately behind the car wheel, therefore where the wheels went the plough must go.

He thought the slot shown in Fig. 4, Plate 53, could be improved by having a drip lip at the bottom of the slot-rail as shown in Fig. 26, for with the drip lip at the top, it might be possible for muddy water to run down the inside of the rail and so get on to the petticoat of the insulator. An objection raised against having the drip lip at the bottom was that the conductor could not be seen, and therefore faults could not be located easily, but this did not

Fig. 26.

Proposed arrangement of Drip Lip at bottom of Slot-rail.

appear to be a valid objection. If there was a fault, one would not need to look for it through the slot; at any rate the conductor could be seen by putting a small mirror in temporarily. The fact that the conductors were not visible would be an additional safeguard against anyone passing a rod or hoop diagonally through the slot, and so making contact with the conductors. The Vignoles section of slot-rail also made it possible to reduce the width presented at the road surface. He thought it would be an improvement to make the insulator with a double petticoat, and cover it over by a small road-box filled in with wood as indicated in Fig. 26.

With regard to the remarks made by other speakers as to width

(Mr. E. Kilburn Scott.)

of slot, it must be remembered that the Buda-Pesth system was
Siemens and Halske's first contract of the kind ; and the slot was
naturally made wider than had since been found to be absolutely
necessary. The same firm subsequently put down a line in Berlin,
where the slot was only $1\frac{3}{16}$ inch, and the author and other
engineers who had been working at the problem had reduced the
opening in the street down to $\frac{3}{4}$ inch. Siemens and Halske had not
the advantage of long practical experience when they built the Buda-
Pesth line, and therefore the work they did was the more creditable
to their engineering staff.*

The author mentioned in the Paper that, owing to the tongue of
the junction of a side-slot having to be made stronger, there must be
another $\frac{1}{2}$ inch of opening, that was to say, at Berlin there was
$1\frac{3}{16}$ inch plus $\frac{1}{2}$ inch at the tongue ; but if the slot was $\frac{3}{4}$ inch it was
only $\frac{3}{4}$ inch plus $\frac{1}{2}$ inch or say $1\frac{1}{4}$ inch, which was not so bad, as its
occurrence would be very rare. He thought that a satisfactory
wheel-flange could be made to work in a $\frac{3}{4}$-inch or $\frac{7}{8}$-inch slot. It
was a choice of two things, and he thought that of the two it would
be better to put up with a narrow wheel-flange rather than have the
extra line of rails required by a centre-slot. The side-slot was of
course much cheaper, but independently of that it was a well-known
fact that shopkeepers along main streets would insist on having
wooden pavement, and as this wore down very quickly the rails were
soon left standing above. The expansion of wooden pavement would
be resisted better by the side-slot, whilst the action of the wheel
would be to counteract any tendency to closure. It was interesting
to note that at Buda-Pesth the wheels running over the slot had
the flange in the centre of the tyre, a method which had the
advantage of wearing the two slot-rails equally.

A description was given in the Paper of the method adopted at
Paris for raising the plough vertically. It had occurred to him that
the plough might be easily raised out of the slot by putting it on a

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* The Buda-Pesth conduit was the first really successful conduit to be
built ; and besides proving the possibility of the side-slot construction such
features as an entirely concrete tube, suspended insulators, and rigid steel
conductor-rails, had since been copied in every successful conduit.

FIG. 28.   *The Lennox Avenue Yoke, New York.*

FIG. 29.   *Centre-slot Yoke, Paris.*

FIG. 27.

Plough in raised position

Working position

FIG. 30.   *Westinghouse Yoke.*

Ins. 12   6   0   1   2   3   4 Ft.

(Mr. E. Kilburn Scott.)

bar arranged transversely across the truck, and fitting the top of the
plough with a small rack and pinion as in Fig. 27 (page 407).   When
the pinion was turned, the plough would rise into the dotted position,
and so be clear of the rails without taking up any head room.
The self-folding plough as used at Buda-Pesth, Berlin, and Brussels,
had worked for years very satisfactorily, so he saw no reason why its
use should not be continued.   Frequent traps along a slot were both
an expense and a nuisance, especially if the wheel must run over
them.   There was no reason why, with improved mechanical
construction, a plough which could be lifted out of the slot anywhere
should not be obtained.   In any case the parts of a plough were like
a trolley wheel, they wanted renewing at intervals.   In the early
conduit constructions he had noticed that the tie-bar was carried
through the web of the track rail as in Fig. 28, thus giving a
redundant frame, that is to say, both the track-rail and slot-rail could
lean over from the expansion of the paving or other cause.   In Paris
the author had carried the tie-bar down to a projection on the yoke,
Fig. 29, and so obtained a triangular framework which made the
slot-rail quite rigid, besides disconnecting the slot-rail from the
track-rail, which was a good feature.   In the conduit used by the
Westinghouse Company, a projection was carried up from the yoke
casting, and then the tie-bar passed through it as shown in Fig. 30 ;
a back nut on either side of the projection kept both rails quite
steady.   The washers inside the track rails were not triangular
section as required by Fig. 29.   Successful electric conduit
construction appeared to be essentially a matter of close attention to
small details, and the author had done excellent service in this
direction.

Mr. WILLIAM R. COOPER said the author had given the capital
cost of a line ; but if he could give any figures for the maintenance,
including the cost of cleaning the conduit, they would be most
valuable.   Such costs, if possible, should not only be expressed in
terms of the car-mile, but should be supplemented by a statement of
the number of car-miles per annum per mile of single track under
which they were obtained.

Mr. JAMES N. SHOOLBRED said it would be admitted on all hands that the Paper had appeared at a most opportune time. Probably owing to the various circumstances which had occurred lately, those only who were acquainted with the ways of tram-owning corporations would appreciate the full value of the appearance of such a Paper at the present time. In the first place it would be shown to the corporations that there was a possibility of combining upon one line the trolley with the conduit systems—a matter, upon which they still remained sceptical, despite that many engineers had repeatedly advised corporations to adopt such a combined system in their towns. Nevertheless many municipalities were still afraid, either of the expense, or of the possibility of making such a combination a success. The Paper however presented the matter in a simple way, and pointed out clearly that the transition from the trolley to the conduit could be made with comparative ease, both in principle and in actual working. It was the question of the extra cost of the conduit system, which—with corporations—barred its introduction. But surely, in the more important thoroughfares in the centre of large and important towns, this extra cost ought not to weigh for a moment in the consideration of their respective corporations. The length over which the conduit might be suitably used in the centre of a town was not generally large, in proportion to the long distance in the suburbs, where the trolley system would still be used. At the present moment one or two corporations, notably Liverpool, had carried the overhead-trolley system right into the very middle of the town. Being a Liverpool man himself, he could testify to the almost universal objection that had been expressed to the way in which the principal streets had been defaced and rendered unsightly by the overhead wires. But this Paper would be quite sufficient in itself to show that by the system advocated therein the above defects in the centre of the city could be remedied with very little inconvenience. Mr. Ferranti had alluded to Manchester. It would be a very great pity if, in the electrical tramways about to be constructed there, a mistake occurred in that city such as had been made in Liverpool, by causing the centre of the city to be defaced in the unnecessary way in which it had been in Liverpool by the overhead-trolley wires.

(Mr. James N. Shoolbred.)

With regard to the details pointed out in the Paper, in effecting the change from the overhead to the underground systems, a distinction had been drawn between the arrangements at Berlin and those at Brussels, and he might add at Dresden and elsewhere. In Berlin it had been pointed out, as an advantage, that the transference from one system to the other could be effected without stopping the car. That might seem a matter of considerable importance, but when it was considered that the point at which the transference took place was generally a very important one, and one where a stopping place would naturally occur, that argument need not weigh so much as it at first seemed to do. For at such a point the line would enter into the populous part of the city, when leaving the suburbs; and a stopping place was almost necessary, not merely for the passengers, but also to make sure, when making the change, that the plough was raised or lowered as the case might be—exactly over where the pit was placed. He was quite sure that the members would all thank the author very much for the way in which he had brought forward the subject; especially at a time when so many electrical tramways were on the point of being constructed in this country. It might prevent a number of mistakes being made in many large towns.

Mr. E. TREMLETT CARTER said he wished to refer to a point which had not been touched upon in the discussion, and about which no mention was made in the Paper, namely, that the conduit system not only did away with that amount of unsightliness which was alleged to be inherent in the overhead-trolley system, but also provided what, from an engineering point of view, was even more important, namely an insulated return for the current from the car. This insulation was considered in certain circumstances to be necessary in order to prevent electrolytic corrosion of gas- and water-mains in the streets. There was more risk of dangerous electrolysis occurring in the cities than in the rural districts, for it was in the cities and not in the rural districts that gas- and water-mains mostly occurred. The conduit therefore was particularly applicable to the city, and the overhead trolley to the rural districts. He could testify to the ease with which

conversion from one system to the other could be effected, having
seen the operation performed on several lines in America, where
conduits had been run with very small slots. By going a short
distance out of London to Kennington, where a cable system was
joined to the horse-car system, one could see what was equivalent
to the conversion from the conduit to the overhead-trolley system.
The car came down from Brixton Hill, the shoe was detached (not
exactly in the same way but occupying about the same time), the
horses were hitched on, and the conversion thus took place—about
the same amount of work as there was involved in converting from
the electric conduit to the overhead-trolley system. It was extremely
important in a country where the bicycle abounded, that the slot
should not be of such a width that "a cat could get through."   A
bicycle could get down a slot where any cat could ; and the safety
of the people from overhead-trolley accidents should not be
counteracted by a holocaust of bicyclists.

Mr. ROGER T. SMITH said there were one or two points affecting
the design of conduits—which probably might not be constructed
under the same conditions as in Paris—on which he would like to
ask the author a few questions. The author had laid great stress
upon one most important point, namely that the depth of the tube
should be reduced as much as possible, so that the interference from
obstructions below the surface might be as little as possible. Pipes
laid along the road might have to be diverted, if they were very
close to the conduit ; but the less the depth of the conduit the less
would one be troubled with interference from service pipes, which
crossed the street from side to side.   During its construction the
conduit took up a considerable amount of road from the general
traffic, and made a great mess ; and to increase unnecessarily the
interference with what was left of the roadway, by taking up and
reducing in level a large number of service pipes, would be a great
disadvantage.

The author had stated that the first point to settle in designing
a conduit was the height of the conductor-bars. Plate 53 showed
two forms of insulators by which the conductor-bars might be fixed.

(Mr. Roger T. Smith.)

In Fig. 3 there was only 2 inches between the surface of the road
and the top of the insulator. That necessitated an iron cover to the
road box. In many cases in England it would not be permitted,
and if a Road Authority demanded that the cover of the box should
be filled with the same material as the pavement of the rest of the
street, one could not use that form of insulator placed in the way
shown in Fig. 3. In the second form shown in Fig. 4, the insulator
was fixed on to the slot-rail. For a good many reasons a 7-inch
slot-rail, which he believed was the depth of that shown in Fig. 7,
was the most suitable depth from considerations of strength and
convenience of paving; but it brought down the top of the
conductor-bar so low—in Paris he believed it was 14 inches—if the
insulator was hung from its flange, that the total depth of the
conduit was very great indeed. It was quite possible to
design other forms of insulators differently fixed, in which the
conductor depth need not be so great. The average distance in
America and many other places was about $12\frac{1}{2}$ inches from the
surface of the road to the top of the conductor-bar. Given that
distance, it remained to be seen what depth below the conductor-bar
one must have in order for the plough to clear mud and water,
because the conduit was a sort of sewer. The author made some
interesting remarks with regard to what had been done in crossing
the Pont d'Alma in Paris, where the depth of conduit below the
conductor-bar was only 4 inches. The author advocated having
conduits of different depths, so as to avoid obstructions when
they occurred. He would like to ask him if the much greater depth
below conductor-bars—9 or 10 inches—shown in Plates 56 and 59, for
the accumulation of mud and water was really necessary. It simply
became a matter of sufficiently numerous sewer connections and
frequent cleaning. In South London a conduit already existed in
the cable line at Brixton. It was an analogous case to the one
under discussion, because the cable in it was kept by its pulley
about 6 inches from the bottom of the conduit, and sagged another
inch, so that at its lowest point it was 5 inches from the bottom of
the conduit. The principle there was that the cable was never
allowed to run in water or mud. There was no difficulty with

5 inches only below the cable in keeping that 5 inches clean at a cost per mile of single track of £60. He would like to ask the author whether he did not consider it worth while, taking into account the advantage it was to have as shallow a conduit as possible, to go to the expense of paying £60, £80, or even £100 per mile of single track a year to keep the conduit constantly clean, rather than have 7, 8, 9 or 10 inches as in some designs below the conductor-bar, thus having the conduit less frequently cleaned and running the risk of deposit, although saving possibly something in maintenance.

Mr. Raworth (page 398) raised a point with regard to the width of the metal either side of the centre-slot in the streets, supposing the centre-slot was adopted. He mentioned the figure of 6 inches. It was quite possible to reduce that to $4\frac{1}{2}$ inches. Of course it was an objection to have so much iron in the middle of the street, but $4\frac{1}{2}$ inches would not very seriously interfere with the ordinary traffic, or cause much inconvenience to horses.

Mr. ALFRED BAKER asked the author's opinion with regard to the design of the yokes. In America, as the author was quite aware, the conduit was of the central-slot construction, the slot itself being about $\frac{3}{4}$ inch. To keep the power service going it was necessary to maintain that width of slot; the slightest slot closure would hang up the whole of the traffic. In America he believed the yokes were designed not only to form the tube but to carry the running rails. He had noticed that in Paris the author had used the yoke which merely formed the tube, simply because it was of side-slot construction; but wherever he had in some cases to go into the centre of the track, he then used a yoke which also carried the rails. He would like to ask the author whether, if he had a centre-slot construction throughout, he would use a yoke to carry the running rails or merely have a yoke designed to carry the slot-rails. The Paper had been most interesting, and he was sure all tramway engineers were extremely obliged to the author for having brought it forward at that particular juncture.

The PRESIDENT said the discussion had been a most interesting one, and that fact would, he thought, be the best recompense the author could have for the trouble he had expended on the Paper which he had brought before the Institution. It showed him that it had been most thoroughly appreciated.

Mr. CONNETT, in reply, said that the question of the width of the slot was one dependent upon whether a side or a centre-slot conduit was used. In the former case the side-slot must be wide in order to carry the flange of the wheel, and it was for that reason that all side-slots were wider than centre-slots. On the side-slot portions of the conduit construction in Paris, the width of 29 mm. or $1\frac{1}{8}$ inch was allowed, which was fully taken advantage of. On the centre-slot it was reduced to 1 inch, which could just as well have been $\frac{3}{4}$ inch. In New York and Washington the width of the slot was about $\frac{5}{8}$ inch. It was gauged during construction to $\frac{3}{4}$ inch, but the slots had a tendency to close about $\frac{1}{8}$ inch, leaving the final width as above given. He thought the slot ought to be originally gauged to $\frac{7}{8}$ inch width to allow for a practical width of $\frac{3}{4}$ inch. With regard to the width of the rail exposed in the street, a special construction could be made to reduce this. Mr. Holroyd Smith had pointed out one, but such a construction had the disadvantage of not allowing the tie-bar to pass through the web of the slot-rail, so that in case of a tight slot there would be no quick means of pulling it to the proper width. He preferred a greater width of rail in the street, which gave this advantage of regulating quickly the width of slot and so giving additional assurance to the operation of the tramway. Concerning the relative advantages of the side-slot compared with the centre-slot, on many occasions he had argued in favour of the centre-slot, especially for the conduit lines of Paris, but in this particular case without success. The authorities would not have another band of iron in the street, and for that reason it was necessary to employ a side-slot conduit. He still thought the centre-slot type was the better and least complicated type of construction, but the side-slot conduit had shown in practice that he had exaggerated its defects, and that in reality it could be made to give excellent results.

In reply to Mr. Kilburn Scott, who had asked whether the insulation of the plough running in the side-slot had ever broken down owing to the car-wheels throwing mud on it, he quoted an occasion on which during a snowstorm salt was put on the tracks, and the salt water was thrown on the ploughs. Under those circumstances a number of them broke down. He had had more or less trouble with the ploughs breaking down. A plough was a most difficult thing to construct, and was in a much more exposed position with a side- than with a centre-slot. In Paris he understood the precaution had now been introduced of using a double set of ploughs and changing them each night so that they might be dried out after each day's run. Since then no trouble had been experienced, but it was found necessary to take this precaution at least during the winter months. There was a disadvantage in building one side-slot on the inner rail and one on the outer rail with double tracks, because streets were crowned and the tracks had to be laid to conform to street cross-section. A conduit on one of the outer rails near the kerb would take all the water from the centre between tracks to the slot so placed. For this reason in his opinion the two slots coincident with the two interior rails was the best construction. The advantage of the conduit in having an insulated circuit was self-evident, especially in England, where the conditions for the return were so severe.

He had been asked to give the cost of working conduit roads. He would give it in a comparative way between conduit and trolley lines. At Brussels, where a long experience had been obtained, and where the accounts were accurately kept so as to differentiate the two costs, the difference was as follows: the conduit system cost $1\frac{1}{4}$ farthing more per car-mile than the trolley system. Including the fixed and amortisation charges this amount was $2\frac{7}{10}$ farthings per car-mile. With regard to the cost of cleaning conduits, in Washington it was £5 10s. 0d. per mile of single track per year. The conduit was cleaned thoroughly twice a year, but the low points and switches, where there was a greater accumulation of dirt, were cleaned quarterly. With regard to the question of what depth of conduit should be allowed under conductor-rails, he still believed

(Mr. Connett.)

that from 8 to 10 inches were necessary, except in very special cases
for short distances. The case under discussion was entirely
different from a cable road, where the operation was not affected if
the cable was running in water, or on accumulated dirt; but with
the conduit system there must be a sufficient area under the
conductor-bar to hold the water which would come from the
heaviest rain-storm—assuming that part of such space was already
filled by accumulated dirt—as fast as it came in. That was
especially necessary on such portions of a road where the gradients
were light. It was best to spend sufficient money on the initial
construction of a conduit rather than to make only a partial success
by having the conduit too shallow. A shallow conduit cost quite
enough, and it was better to make it right at the start by insuring
the continuous operation of the road under ordinary climatic
conditions.

When he was in America it had never occurred to him to design
any other form of yoke than that which carried both the slot and
wheel rails, but he found afterwards that it was only necessary to
inspect the electric conduit constructions of the Continent and the
cable roads of England to see that such a form of yoke was rather
a luxury than a necessity. The iron used to carry the wheel
rails was simply useless metal. In any future centre-slot work he
would adopt the general type of yoke which he had used for side-
slot conduits, and not attempt to carry the wheel rails on anything
but a concrete foundation.

Communications.

Mr. HANS RENOLD wrote that he took an interest in the conduit
system as a mechanical engineer only, and thought it was the only
one worth having in cities. He had had several opportunities
of watching and inspecting it in New York, Washington, and other
American cities. At one time New York and Brooklyn had been
covered with trolley wires; now at great expense these were to a

great extent taken away in New York, where they were still removing some of the remaining trolley lines, and putting in their place the conduit system.   In his opinion men of such business capabilities as the Americans had proved themselves to be would not make such a change without having a good reason.   There could be no doubt that, when this system was well built and the first cost not parsimoniously treated, there was nothing hitherto known which gave such good results all round, and was so capable of mastering heavy traffic, as the conduit system.

Mr. J. EDWARD WALLER wrote that he had read with much interest the valuable contribution to tramway literature represented by Mr. Connett's Paper; but there were one or two matters in regard to which he was not entirely in accord with the author.   The author remarked (page 377) that "with the limited clearances in a conduit there can be no other practical method than that of employing rigid conductor-bars."   He ventured to think that a good deal might be said in favour of a flexible conductor.   In the first place a rigid conductor involved more frequent insulators, and consequently more frequent hatchways than were necessary with a flexible conductor; and these insulators were more liable to injury, owing to the mechanical strain upon them by rigid conductors, than were insulators merely supporting a flexible conductor and being subjected to but little mechanical strain.   Secondly a rigid conductor had to be put into place during the construction of the tube, and could not be removed or renewed without considerable interference with the road surface.   On the other hand a flexible conductor could be placed in position through the slot after the construction of the road was complete, and could of course be renewed with equal facility. Thirdly the cost of construction with a flexible conductor was less than with a rigid conductor, mainly by reason of the smaller number of hatches and insulators which were required.

In respect to the question of side-rail conduit versus central conduit, he agreed with the author that, from an engineering point of view, the central conduit was to be preferred, but perhaps not entirely for the same reasons as those given by Mr. Connett.   It

(Mr. J. Edward Waller.)

appeared that the author's principal contention was that there was
risk of the plough missing the points in both methods, but that the
objectionable result in the case of a central conduit could be much
minimised, while a serious injury and delay would be consequent in
the case of a side-rail conduit. It appeared to the writer however
that there should be little or no risk of the plough taking a different
track to the car-wheels on a side-rail conduit, seeing that the same
tongue or switch would guide both the wheels and the plough-shank,
while the risk would be much increased with a central conduit,
owing to separate points being necessary and to the danger of the
two points failing to act together.

His objection to the side-rail conduit system was two-fold.
First with a double conductor in the conduit—and he assumed that
in any conduit system the advantages of a double conductor would
be availed of—it was impracticable, where the conduit was placed
under the side-rail, to have a vertical support to the rail on which
the car-wheel ran, and that owing to the necessity of these rails
overhanging the side of the conduit, a greater strength of casting,
or a greater number of yokes would be necessary than in the case
of the central conduit. The second objection—and the more
serious one—was that the curves on the running track of a
side-rail conduit would, at the turn-outs and junctions, have to
be made extremely sharp to avoid an impracticable length of
cantilever at the junction of the two conduits, and that even
with the sharpest possible curves the overhang of the point
would be such as to involve a greater depth from the surface of the
road to the crown of the conduit, that is to say, to the underside of
the point casting, than is desirable both from the point of view of
cost, and more particularly from the point of view of occasioning a
greater depth of construction throughout the conduit. This difficulty
was entirely obviated in a central conduit, as of course the curves
for the plough could be very much sharper than those practicable
for the tramcar truck. Probably where side conduits had to be
adopted some such device as that suggested by the author would be
desirable, so that at points and junctions the conduit should be
deflected from the side to the centre.

The point in the Paper to which he was most desirous of drawing attention was that of cost, and he could not but think that the author had greatly over-estimated the cost of the construction of a conduit tramway in this country. It appeared to the writer that the principal interest in respect to the cost was a question of comparison between a line constructed on the conduit system and one constructed on the overhead system; and with this object in view, several items might be, he thought, eliminated from the author's estimates, all of which would not arise in all tramways, and which, where they did arise, would be applicable equally to an overhead or conduit tramway. The items to which he referred were as follows :—Temporary track, special track work with hardened centres, and feeder ducts. As regards obstructions he thought that this item might also well be omitted, as the only *additional* surface obstructions which would be met with on a conduit line would be the possible movement of a few manholes and valve boxes, which should not represent anything like £1,000 per mile of single line on an ordinary tramway. Of course, if a conduit tramway involved alteration of any considerable number of mains, the total cost might be almost any sum; but this was a matter which could only be dealt with in each specific case, and he did not think in this country one was likely to meet any very large mains with less than 2 feet cover. Service pipes might of course require to be altered either with a conduit system or with an overhead system. The additional number of pipes to be altered in the conduit system might perhaps be entirely neglected, as only such pipes as were situated in the space between 1 foot below the surface of the road and 18 inches below the road surface could be regarded as extra; those less than 12 inches below the surface would have to be altered in the case of ordinary tramway construction, and those more than 18 inches below the surface would be below the bottom of the conduit, and therefore should occasion no special difficulty in dealing with.

He thought that the yokes proposed by the author were unnecessarily heavy, and the number which he proposed to be used was rather more than were essential. The tests which he had himself carried out in this matter led him to the conclusion that

(Mr. J. Edward Waller.)

yokes of ample strength did not need to weigh more than about 165 lbs. each, as against the author's figure of 210 lbs.; and he was of opinion that they need not be placed at closer intervals than 4 feet apart. The yoke to which he referred was provided with wings tying the running rails to the conduit and consequently to each other, and therefore with this construction, tie-bars, which the author included, could be dispensed with.

He also considered the author's prices too high, from his experience of the cost of tramway construction, both for ordinary work and conduit work. Taking for instance the yokes which were priced at £10 per ton, he might state that a few years back he obtained very similar yokes at a price of £5 10s. 0d. per ton. He had however, considered that, having regard to the increase in prices, and also to the necessity of providing for a certain amount of machining on the jaws, and having regard to the further fact that the design of yoke on which he was figuring was a little more complicated than that which he had previously obtained, he had increased the figure in his estimate. In order to make a fair comparison between the cost of a conduit line, and one on the overhead system, he thought it preferable to deal with a mile of double track, rather than a mile of single track, first because conduits were most likely to be used in busy towns with large traffic, warranting the use of double lines; secondly because there was little difference in the cost of the overhead equipment of a single line and a double line, and a comparison based on single lines would therefore show too favourably to the conduit system; and thirdly because with a single line, provision would have to be made for points and crossings at passing places, and the direct comparison of a straight length of single line on the two systems would be misleading. He had pleasure in appending two estimates, one for a mile of double line constructed on a conduit system, the other for a mile of double line on the overhead system; and in both these estimates he had left out feeders and feeder ducts, the cost of which could not properly be standardized. From these estimates, it would be seen that he placed the cost of a mile of double line with central conduit, on the 4 feet 8½ inches gauge, with rigid

conductors, at £18,314 5s. 0d., as against the author's estimate of £25,760 10s. 0d., the latter figure being exclusive of the following items included in Mr. Connett's detailed estimate, amounting to £7,206 0s. 0d., namely special track work, temporary track, obstructions, and feeder ducts.

The writer's estimate for a similar mile of double line, with overhead equipment, was £12,853 10s. 0d., showing the cost of the conduit system for a mile of double track, as £5,460 15s. 0d. in excess of the cost of a mile on the overhead.   The author had not given an estimate of an overhead system for the purposes of comparison, but had stated in general terms that the difference per mile of single track would be from £5,000 to £5,500 per mile more for a conduit route than for a trolley route, under the same conditions—a difference of about double that which the writer had arrived at.   This difference of £5,461 which he had estimated would, he thought, be reduced to something like £4,437 per mile of double track with a side-rail conduit with rigid conductor-bars, and by a further £1,063 per mile of double track with a flexible conductor.

Conduit System of Electric Traction (Centre Conduit).
Estimated Cost per Mile of Double Track.
(4 ft. 8½ ins. gauge.)

			At	£	s.	d.
282 tons .	.	Wheel rails . .	. £7 per ton .	1,974	0	0
10½ tons .	.	Fishplates . .	. £7 ,,	73	10	0
157 tons .	.	Slot-rails . . .	. £7 ,,	1,099	0	0
5 tons .	.	Fishplates . .	. £7 ,,	35	0	0
88 tons .	.	Conductor-rails—28 lbs.	. £8 ,,	704	0	0
9·32 tons	.	Bolts and washers, &c.	. £18 .	149	16	0
1,510 .	.	Insulators complete with clips . . .	. 6s. 2d. each .	434	0	0
135 tons .	.	Cast yokes—165 lbs. .	. £7 10s. each .	1,001	10	0
1,408 .	.	Hatch covers . .	. 5s. each .	352	0	0
31 tons 13 cwt. .	.	Angles for roof . .	. £7 per ton .	221	11	0
2,268 c. yds.	.	Concrete for tube and paving	£1 5s. per c. yd.	2,835	0	0
8,800 sq. yds. .	.	Wood paving . .	. 14s. per sq. yd.	6,160	0	0
			Carried forward	15,039	7	0

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				£	s.	d.
		Brought forward		15,039	7	0
		At				
4,160 c. yds.	. Excavation . . .	3s. 6d. per c. yd.		730	16	0
	Sewer connections and					
	manholes, say. . .	. . .		352	0	0
10,560 ft. .	. Platelaying . .	. 2s. 6d. per ft. .		1,320	0	0
				17,442	3	0
	Extras and contingencies .	5 per cent. .		872	2	0
Total cost of Double track per mile	. . . .	.		£18,314	5	0

Overhead System of Electric Traction.
Estimated Cost per Mile of Double Track.
(4 ft. 8½ ins. gauge.)

			At	£	s.	d.
3,128 c. yds.	. Excavation, 12 inches deep	3s. per c. yd.	.	469	4	0
1,564 c. yds.	. Concrete, 6 inches thick .	16s. per c. yd.	.	1,251	4	0
8,800 sq. yds.	. Paving, wood blocks and					
	laying	14s. per c. yd.	.	6,160	0	0
282 tons .	. Steel rails, 90 lbs. per yd. .	£7 per ton	.	1,974	0	0
10½ tons .	. Fishplates . . .	£7 ,,	.	73	10	0
3 tons 16 cwt.	. Bolts	£18 ,,	.	68	8	0
1,408 .	. Tie-bars	1s. 6d. each	.	211	4	0
3,520 yds.	. Labour, laying permanent					
	way	1s. 6d. per yd. .		264	0	0
	Overhead equipment, in-					
	cluding poles, brackets,					
	trolley wires, feeder switch					
	pillars	.	.	1,450	0	0
	Bonding	.	.	320	0	0
				12,241	10	0
	Extras and contingencies	. 5 per cent.	.	612	0	0
Total cost of Double track per mile	. . .	.		. £12,853	10	0

Mr. CONNETT, in reply to the communications, wrote that the remark of Mr. Hans Renold (page 417), that at one time New York and Brooklyn had been covered with trolley wires, was misleading. In Brooklyn all the surface tramways used the trolley system, and there was no prospect of its being discontinued. In New York the trolley was never allowed, except for a short length of track on what was known as the " Huckleberry " road in the extreme upper part of the city. Therefore the conduit roads in New York did not replace the trolley, but rather the horse and cable.

He could not agree with Mr. Waller that a rigid conductor involved more frequent insulators than were necessary with a flexible conductor (page 417). On the contrary a rigid conductor not being subject to the variations in position of a flexible wire required fewer insulators, especially so on curves. The insulators shown in the Plates had never given any trouble mechanically. For instance the Washington insulator, tested with a ton weight slung to the bolt which carried the conductor-rails, showed no signs of failure. It was not the strain put on them by carrying the steel conductor-bars which determined their spacing and thereby their number. What fixed this was the bending of the conductor-bars themselves, due to the side pressure exerted on them by the plough-shoes pressed outwardly by springs. If the bars should yield too much between the insulators, the result would be loss of contact.

Traps in the slot-rail should always be provided at a fixed distance apart to provide for taking out and renewing conductor-rails at any time, without disturbing the road surface in any manner. Whatever advantage there might be in placing the conductors after the completion of the road could just as well be realised with the rigid as with the flexible type. It might be of interest to state that the conductor-bars on the Washington road were put in a long time after the completion of the conduits, and after the horse cars had been diverted to the new tracks. They were placed in position at the rate of a mile of track per diem, and the work was completed only just in advance of the opening of the road with electric traction. This was done expressly so that their contact surface would not get coated with rust. If the author's contention that the same number

(Mr. Connett.)

of, and probably more, insulators were needed for a flexible than a rigid conductor, the economy in construction for the former would not be realised.

Mr. Waller's remarks about the minimised risk of accident with side-slot points, because both car and plough must go in the same way, only held true in the case of an intersection of two conduits. For the more usual case of a turn-out from the conduit of an ordinary track, the point if wrongly set would guide the car from the conduit track; and the slot being solidly obstructed by the point, the plough was necessarily wrecked. For this the author advised the deflection to the centre-slot, with the consequent slipping off of the plough at the ends of the carrier-guides in case of a misplaced point. In the case of a slot-switch the centre-slot deflection was advised because the side-slot slot-point had inherent difficulties which it was wise to avoid, even by the addition of a point to be worked in unison with the wheel-rail points. The author failed to grasp Mr. Waller's contention that the serious difficulty with a side-slot slot-point was that it had to be made with a sharp radius to avoid undue overhang, while in the centre-slot construction the track points could be made with large radius, and the slot-point with a small one. The centre-slot slot-point being concentric with the wheel-rail points, the overhang became the same in each case, and there was no advantage in one construction over the other, except that with the centre-slot the movable point did not have to bear the car-wheels; therefore it could be comparatively light, and placed below the top surface of the rails to serve simply as a guide to the plough.

He hoped that Mr. Waller was right when he said that the author had greatly over-estimated the cost of conduit construction in this country. The Table (pages 395–6) was only a rough estimate, as any such attempt must be.

It was necessary in giving the cost of a conduit road to start with some specific design; and the author considered the type of side-slot conduit used in Paris moved to the centre-slot position. The author believed that a conduit, at least as strong as this one had proved itself to be, would be necessary for the conditions of the larger cities of Great Britain. The quantities of material had been

given, so that any engineer could use whatever unit prices he might deem proper, the latter varying at different times and in different places.   But to economise by using lesser quantities than those indicated might result in unduly weakening the conduit, or making it too small for the purpose intended.   The author could not agree with Mr. Waller about the weight of yokes.   In his estimate he gave 67½ tons per mile of track with unit weight of 165 lbs.   The spacing from this would be about 5 feet 6 inches centre to centre. If yokes of this weight, having a certain amount of non-effective metal to carry the wheel rails, and spaced this distance, would be effective against slot-closure, then the author had misinterpreted the results of his actual experience.   In practice more material was used and work done than the amounts shown necessary by the drawings. For instance, there were sub-surface obstructions requiring trenches, which had to be paved over again.   The concrete for the tube was increased, because it was impracticable to excavate the trench to theoretical lines.   The excavation was costly because it should be done with forms and templates, otherwise the tube would require an undue quantity of concrete.   The Table (pages 395–6), so far as quantities were concerned, was based on the results of final and not preliminary estimates.   He attempted to give values for all the expenses which entered into a conduit construction ; and it was for this reason that approximate costs of special track-work, sub-surface obstructions and ducts, etc., were introduced, though he was quite aware of the fact that for these items it was impossible to give anything more than an average figure, except for a specific case.

The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1901.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 19th April 1901, at Eight o'clock p.m.; WILLIAM H. MAW, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty-eight candidates were found to be duly elected :—

MEMBERS.

ANDERSON, JOHN REID, . . .	London.
BEHR, HANS CHARLES, . . .	Cape Town.
BELL, EDWIN, ...	Gosport.
CLARKE, GEORGE GRANVILLE, . .	Birmingham.
HODGSON, EALEY, ...	Erith.
LONGBOTHAM, ROBERT HALL, . .	Wakefield.
MARSHALL, HERMANN DICKENSON, .	Gainsborough.
OLDHAM, FRED, ...	Dukinfield.
POORE, GEORGE BENTLEY, . . .	Johannesburg.
SMITH, DANIEL, ...	Wolverhampton.

ASSOCIATE MEMBERS.

ADAMS, CHARLES WILLIAM, . .	London.
CULLUM, WILLIAM WRIGHT, . .	London.

DELACOUR, HARRY MARK, . . .	London.
DRAYCOTT, GEORGE EDWIN, . .	London.
FRYER, TOM JEFFERSON, . . .	Sheffield.
GODDARD, WILLIAM HERBERT, . .	Buenos Aires.
GOULDING, BENJAMIN JOSEPH JOHN, .	London.
GRANT, DANIEL JOHN, . . .	Belfast.
HAWKINS, LAWRENCE GRANVILLE, .	Lisbon.
KEEGAN, FRANK JOHN, . . .	Coventry.
KORTRIGHT, PERCY FORBES, . .	Leeds.
MACCURRACH, DOUGLAS COCHRANE, .	Middlesbrough.
NEWTON, HENRY EDWARD, . . .	London.
PINKNEY, THOMAS SAMUEL, . .	Baku, Russia.
PRYOR, HENRY ALLEN, . . .	London.
RITCHIE, THOMAS EDWARD, . .	Manchester.
ROBINSON, HERBERT, . . .	Dublin.
ROSS, FREDERICK GEORGE, . .	Bombay.
ROWE, FRANK LANDER, . . .	London.
RUSHWORTH, GEORGE WILLIAM, . .	Colne, Lancs.
SHAW, IRVINE, ...	Darlington.
SIMPSON, WALTER, ...	Manchester.
SMITH, ADAM, ...	Chesterfield.
SMITH, ALFRED, ...	Wolverhampton.
VISICK, CHARLES, ...	Devoran.
WEBB, JOHN FREDERICK, . . .	London.
WILLIAMS, DAVID THOMAS, . .	Barry, near Cardiff.
WILSON, RICHARD DAWES, . .	Kew.

GRADUATES.

ARMITSTEAD, HENRY, . . .	Manchester.
CROFT, FRANK, ...	Bradford.
EVERETT, GEORGE ELIOT, . .	Cardiff.
GAUVAIN, WILLIAM PERCIVAL, . .	Leeds.
HAYES, HERBERT CHARLES, . .	London.
HIBBERD, FREDERICK CHARLES, . .	London.
KELSEY, PERCY WILLIAM, . .	London.

MERRETT, JOHN ALFRED, . . . London.
SOAMES, ERNEST ARTHUR, . . . London.
TURNBULL, WALTER ALEXANDER. . . Sunderland.

TRANSFERENCES.

It was also announced that the following four Transferences had been made by the Council:—

Associate Members to Members.

DADINA, HORMUZ MINOCHER, . . Bombay.
GRAY, ALEXANDER CUTHILL, . . Rio Grande do Sul.
MOULE, FREDERICK OSWALD, . . Lincoln.
WILLIS, EDWARD TURNLEY, . . Tamworth.

The PRESIDENT then delivered his Inaugural Address.

The Meeting terminated at Twenty minutes past Nine o'clock. The attendance was 123 Members and 59 Visitors.

ADDRESS BY THE PRESIDENT,

WILLIAM H. MAW, ESQ.

In delivering before this Institution the first Presidential Address
in a new century, there is naturally a temptation to indulge in a
historical retrospect, and to trace out, in greater or less detail, the
developments which have taken place in Mechanical Engineering
during the century which has just been completed. Such a
temptation however is, I think, one which it is well to resist; and
this evening, if I refer to historical matters at all, it will only be in
an incidental way, and as illustrating some special points to which I
wish to direct your attention. In other words, I propose to speak
of the present, and not of the past.

In considering the present position of the mechanical engineer,
the most striking features are, undoubtedly, the universality of his
work and the wideness of his interests. When we remember how
the developments of civilised life depend upon the products of
mechanical science, it is astonishing how inadequately the
ramifications of mechanical engineering practice are appreciated by
the average citizen. It is only by entering into very considerable
detail that the real facts of the case can be brought home to such a
person; and these facts are, without doubt, very striking. They prove
that, from the time we rise in the morning to the time we retire to
rest, there is scarcely a moment during which we are not indebted
to the mechanical engineer for our necessities and our comforts.
His work pervades our very existence. It may easily be shown that
there is scarcely an article we use in the production of which some
mechanical device has not been employed. Our daily wants include
the products of textile machinery, mining and metallurgical

appliances of the most varied description, metal-working machinery, machinery of various kinds for the treatment of food products— including milling machinery, sugar-making and refining machinery, agricultural machinery, and so on—paper-making and printing machinery, sewing and other machinery used in the manufacture of wearing apparel, and numberless other mechanical devices of a minor kind.   Then again the machinery constituting the mechanical equipment of our waterworks, and that of our works for lighting by gas or electricity, &c., contribute in a most important degree to our health and comfort.   Moreover, the mechanical engineer, in addition to designing and constructing all this varied machinery, has to supply the motive power by which it is operated, and the tools by which both the machinery and its motors are made ; while, beyond all, it is to him that we are in the main indebted for the effective working of our modern systems of transport by land and sea, and for the blessings which they confer.

It may perhaps be thought that addressing, as I am, an audience of engineers, to whom these facts must be well known, it is unnecessary that I should even mention them ; but I do so from a conviction that, though this knowledge may be general, the lessons which these facts teach are not always so thoroughly appreciated as they should be, even by those most familiar with the facts themselves. For instance, let us consider briefly how they bear upon the technical training which it is desirable should be given to our young mechanical engineers.

I am particularly desirous that any criticisms which I may make, bearing on the methods of teaching adopted at our technical colleges, should not be interpreted as indicating any doubt whatever on my part with regard to the great usefulness and general efficiency of such institutions.   On the contrary, I have the highest respect for the excellent work they are doing, and I regard them as absolutely essential to the proper training of our rising generation of engineers. But technical colleges are institutions of comparatively recent growth in this country, and I think that no one who has studied their methods will claim that they have even approximately reached perfection.   Nor is it reasonable to suppose that such an end could

have been attained. Such colleges have really to deal with difficulties of no ordinary kind. They have to take a number of boys or young men of greatly differing temperaments and ability, who have been educated in a great variety of ways ; and they have, within a comparatively brief period, to impart to these students a large amount of special knowledge calculated to assist them in their future professional careers.

To use a railway metaphor, the technical college may be regarded as a kind of cross-over road, diverting the student from the line of scholastic training to that of independent thought and action, on which he will have to make his way in the journey of life. Now just as such a cross-over road should have its curves so arranged as to allow of a train passing over it with the least possible shock or damage, and with as small a reduction as possible of the energy which may be stored in it, so also the training in our colleges should be framed so as to unite smoothly at the one end with the student's previous scholastic teaching, and at the other with his subsequent workshop or office practice.

Nothing is more disheartening to a student than to find at some stage in his career that he has been devoting time to learning things which are not only useless to him, but which it is really desirable that he should unlearn ; while, on the other hand, he has failed to acquire knowledge of which he stands badly in need. Yet this is a far too frequent experience with boys entering technical colleges from our public schools. Matters are, I am glad to say, improving in this respect, and many of our large schools are conducted on less hard-and-fast lines than formerly, and are thus materially aiding the technical colleges in the early stages of their work. The changes, however, which have so far been made in this direction are of a very limited extent compared with those really required, and there is still left to be done at the technical college much educational work which ought to have been done at school, the result being a waste of valuable time. This matter is one which merits the most careful attention of all interested in technical education.

But the transition from school to college is, as I have pointed out, not the only junction at which the course of the engineering

student may experience shock, with its consequent loss of energy. There is the other—and in some respects even more important— junction between the college training and the future professional career; and it is of this junction that I wish more especially to say a few words on the present occasion. In the case of the earlier junction, that between school and college, there are two elements which may be modified to secure a smooth union, namely the final stages of the school training and the earlier stages of the training at college; in the case of the second junction, there is at present practically only one changeable element—the practice of our engineering workshops and offices being generally fixed by other considerations than the education of students—and it thus follows that it is to the adaptability of the college course that we have to look to secure our desired continuity in the system of professional training. Now it is at this point especially that I think the methods of our college authorities are, in certain cases, somewhat open to criticism from a mechanical engineer's point of view.

And here I may remark that, in considering the education of young mechanical engineers, it is most desirable that we should not lose sight of certain questions of time and expense which have a most important practical bearing on the course of such training. If cost were no object, and if it were immaterial at what age the young engineer became a self-supporting member of the community, the problem to be dealt with would be a much easier one. But in the vast majority of cases these points are matters of very serious import; and parents, when sending their sons to technical colleges, very justifiably expect that the time thus occupied, and the expense thus incurred, shall be at least partially compensated for by a proportionally rapid advancement in the subsequent stages of professional training. There is in this respect a vast difference between the position of our technical colleges and that of our older universities, which it is important to bear in mind.

In commencing this Address, I referred to the enormous number of branches into which the work of the modern mechanical engineer is divided; and it must be quite evident that many of these branches are of such a highly special character that success in them can only

be obtained by an equally special training. It is this fact which, I think, is not quite so generally appreciated as it should be by our technical college authorities. At present the practice in most of our colleges tends to effectively introduce students to a very limited number of the branches of mechanical engineering ; the consequence is that young men flock into departments of the profession already crowded, or, if they enter less popular branches, find themselves to a great extent without that special preparation for their career which it should have been the object of their college life to supply.

No one is more opposed than I am to the too-early specialising of a young engineer's training. To specialise too early means, generally, a narrowing of the field of view which is most detrimental to future success. Moreover it is not until the engineering student has made substantial progress in his studies that he is really in a position to determine for which branch of his profession his predilections, his ability, or his opportunities best fit him. There is thus no good reason for making any changes in the earlier stages of the technical college course, when the student should be acquiring that sound knowledge of general principles, and those habits of careful exactness in his work, which every mechanical engineer should possess, whatever may be the branch of his profession which he ultimately takes up. But there comes a time when every engineer must specialise, if he really wants to attain anything more than a subordinate position ; and my view is that this specialisation had better be at least commenced during the college career rather than subsequently—the student devoting the latter part of his course at college to the acquirement of a knowledge of the special principles which underlie practice in the particular branch of the profession to which he is about to enter. This means that our college authorities must take a wider view of their responsibilities than many of them at present do. It will also probably mean in the future that certain colleges will acquire a reputation for certain branches of work; and, in order that full effect may be given to this development, it may possibly be desirable that arrangements shall be made whereby a student, after passing through the early

stages of his course—and after arriving at some decision as to the character of his future career—can be transferred from one college to another for the completion of his special instruction.

For some branches of our work, our colleges, as they exist, afford an admirable training. Thus the principles of steam - engine construction and working are usually very fully taught, and the student is rendered familiar with modes of testing both materials and motors, and other kindred matters. The result is that a student, entering works where steam-engines are built, at once feels more or less at home ; and he acquires a knowledge of shop work much more quickly and easily than he would have done, had he not had his previous college experience. But the young engineer who enters some less-known branch—say, for instance, the construction of ordnance, of textile or milling machinery, or even of machine tools, such as are used in advanced practice—finds himself on far less familiar ground, and greatly in want of preliminary special training. In fact he feels himself in the position to which I have already referred as so undesirable—namely that he has spent time acquiring knowledge which is of little immediate practical use to him, and that he has done this at the expense of not learning things which he badly wants to know. Of course, it is quite impossible for the educational equipment of our technical colleges to comprise plant relating to more than a very restricted number of branches of mechanical engineering work, while the knowledge of a staff of professors and the variety of the training they are capable of imparting are necessarily finite ; but notwithstanding this it will, I believe, be found possible to do much more than is now generally done to give a special character to the final stages of a college course, and to encourage students to take a wider view than most of them now do of the possibilities of the career upon which they are entering.

Just as one of the chief objects of scholastic life is to teach a boy how to learn, so, I consider, one of the chief aims of technical college training should be to develop independent thought and action in a student, and to encourage him in individual research. In saying this, I use the word " research " in perhaps a somewhat restricted sense. I do not mean that a student should be expected, during his

college days, to make new discoveries; but that he should be
urged to investigate for himself the reasons for current practice,
and—in plain English—" to get to the bottom of things," and not to
rely upon rules and formulæ of the foundations of which he knows
little or nothing. It is no uncommon thing for a young engineer,
after he has been a few months in a workshop, to begin to realise
how many opportunities he has wasted during his career at college.
Knowledge which he had regarded as complete and definite he finds
to be most incomplete and indefinite, and he is apt to be disheartened
by feeling that his preliminary training has lacked that thoroughness
which alone can secure success. This is a state of affairs which
could be much improved by the adoption of that specialisation in the
final stages of college work which I have already advocated. In
these final stages, the student should add to the knowledge of general
principles which he has already acquired, the most detailed
information available relating to the particular branch of the
profession which he is about to take up, and should endeavour, as far
as possible, to anticipate his wants in the workshop. Moreover, he
should make himself familiar with the methods by which he can
further advance such knowledge after he leaves college, and is
deprived of the assistance of his professors. This last I regard as an
important point. Those who have been much brought into contact
with engineering students when entering their workshop life, well
know how deficient a large proportion of them are in their knowledge
of the literature bearing upon the special branch of work they are
taking up—particularly of literature in any other language but their
own. In this latter respect our English engineering students are, as
a rule, at a decided disadvantage as compared with those on the
Continent.

A point to which the attention of engineering students should be
very specially directed, during the later portion of their college
training, is the necessity for the careful study of constructive detail.
By this I do not mean merely that the student should get a general
knowledge of a number of forms given to chief parts of engines or
machinery, but that he should endeavour earnestly to make himself
acquainted with what I may term the anatomy of details; that is to

say, he should examine the units of which they are composed, and study the manner in which such units are made : their materials, the provisions for their adjustment and lubrication—when such adjustment and lubrication are necessary—the manner in which wear takes place, and so on. Perfection of detail is the very essence of successful mechanical engineering practice ; and to the careful observer, the study of a boiler which is being broken up, or of an engine or machine which is being stripped for repair, will afford an endless number of lessons of the greatest practical value. Such study of detail, moreover, besides being instructive in itself, will serve a most useful purpose in cultivating habits of observation, and in bringing home to the student the necessity of supplementing his theoretical knowledge by the teachings of practice.

In making these suggestions I fully recognise the difficulty which exists in obtaining anything like a thorough knowledge of the wants of engineering students during their workshop life, the more so as these wants differ so greatly in individual cases. There are however two sources of such knowledge which might, it appears to me, be more utilised than they have hitherto been. For one of these aids we must be dependent upon students themselves. There are, in connection with most of our technical colleges, engineering societies for the reading and discussion of papers ; and if past students could be persuaded to contribute to these societies papers setting forth clearly and freely their difficulties in the workshops, and indicating the points in their theoretical training to which they had failed to attach sufficient importance while at college, they would render a great service, not only to the students who were succeeding them, but, indirectly, to the professors also.

The other source of such knowledge as we are seeking is to be found in the experience of the teachers in such of our technical schools as deal with those already engaged in practical work. Of course, the great bulk of the students in such schools have never had any technical college training—and in fact comparatively little theoretical training of any kind—but they also include a fair sprinkling of young engineers who, having passed through a college course, nevertheless find it desirable to supplement it in various

ways.   The lessons to be drawn from the deficiencies of such
students would, I believe, be in many cases of much interest and
value.   It has to be remembered that, as a rule, the intercourse
between the professors of our technical colleges and their past
students is of a very limited kind ; and thus defects in the system of
training, which would be promptly remedied if they were known to
be defects, have strong chances of being perpetuated simply because
they are unrecognised.   That this state of affairs should be improved,
no one, I am sure, could be more desirous than the professors
themselves.

It cannot be too thoroughly appreciated that the vast development
of mechanical engineering work, which has been going on in the
past half-century, and which is still going on at an ever-increasing
rate, is producing a most important change in the conditions which
secure both professional and commercial success.   In the old days
our leading firms of mechanical engineers had comparatively few
customers ; and they had, as a rule, to meet the great variety of
requirements of those customers to the best of their ability.
Repetition work was comparatively rare, and success depended
largely on resourcefulness and the power of entering thoroughly into
the conditions to be fulfilled.   Nowadays the successful mechanical
engineer is not he who makes a great variety of things for the few,
but a small variety of things for the many, at the same time
producing those few things in the most perfect way.   Such a
manufacturer will not be confined to his own country for the sale of
the machinery he produces, but will be able to supply the markets of
the world.

One of the most striking differences between savage and civilised
life is that due to the development of means of transport.   The
uncivilised man must, as a rule, draw his supplies from his immediate
surroundings, while the inhabitant of a country like ours has
practically the products of the whole world at his command.   Year
by year the barriers of time and space which divide nations are
being reduced by the improvements in steam navigation, in railways,
and in the means of telegraphic communication ; and not only are
we thus enabled to draw our supplies from all quarters with

ever-increasing facility, but we are also enabled more and more easily to distribute our products to distant markets, instead of being compelled to find an outlet for them near home. But while we are able to do this, other nations are also able to do the same thing. New countries are continually being opened up, and these countries will demand for their development the bountiful aid of the mechanical engineer. They will need railways and rolling stock, bridges and structural work, machinery of endless kinds; and, as a rule, they may be relied upon to satisfy these requirements by purchases in the most favourable markets, unbiassed by any sentimental regards for kinship. Now, what we have to face in this new century is the cosmopolitan competition which this state of affairs engenders, and this is a matter which demands the most earnest consideration from all interested in our national progress.

I have said that the most successful mechanical engineers of the present day are, as a rule, those who turn out a small variety of products; but I do not by this mean that the successful mechanical engineer is one who takes a narrow view of his profession or its responsibilities. This is certainly very far from being the case. An engineer may manufacture but few machines or other products, and yet may be—and, if he is to be really successful, should be—a man of extensive general knowledge and of wide experience in the practice of his profession. But he must concentrate this knowledge and this experience, and bring them all to bear on the work he has in hand, so as to produce that work at the lowest possible cost and—what is even more important—of the highest possible quality. Experience shows clearly that mere lowness of price is not in itself an inducement to purchasers; and the maker of an engine of exceptional economy, or of a machine tool which excels its competitors in the quantity or quality of the work it turns out, will never find difficulty in obtaining proportionately good prices for his productions.

Much is said from time to time about "repetition work," and working to standard patterns; but even amongst those who should know better there is often much vagueness as to the meanings attached to these terms. There is of course nothing new in the

adoption of certain standard dimensions, nor in the making parts of
similar engines or machines so that they are interchangeable. Such
interchangeability of parts has been common—in locomotive practice,
at all events—for over forty years. But there is something new in
the most modern methods of carrying out such practice, and these
methods have begun to exercise an important influence in many ways
on the procedure in engineering works. In considering these modern
methods and comparing them with older practice, we are at once
struck by two special differences. The first of these is the
definiteness with which the sizes of parts are now fixed. The fitting
of one part to another is no longer a question of working to gauges
of which the absolute sizes are unknown, but of working to sizes
which are definitely fixed and stated, and which are at any time
capable of reproduction. Moreover the limits of deviation from
these exact sizes are rigorously fixed also. To carry out this system
means the general provision of instruments for accurate measurement,
which were formerly only to be found in a very few special
establishments, such as those engaged in the manufacture of
small-arms and ordnance. It means also the possession of skill in
the use of such measuring appliances, and a cultivation in the
workmen of a thorough appreciation of the value of small units. It
further means the establishment of a thorough inspection of the
work turned out, and the prompt rejection of any pieces which do
not come up to the standard of accuracy determined upon.

The second striking difference in practice to which I have just
referred is the manner in which, in our most advanced works, the
mode of manufacture of any particular detail which is to be
reproduced in quantities is determined. According to older practice,
the office work in connection with such a detail would have
terminated with the design of the detail and the preparation of the
working drawings; the manner in which the detail should be
actually made, and the tools to be employed upon it, were left to be
determined in the workshops. According to the new system, on
the other hand, not only is such a detail designed in the office, but
before the drawings are sent into the works it is determined exactly
how its manufacture shall be carried out, the successive processes it

is to undergo being specified, and the machines and tools used in them to perform these processes being fixed. Such a system as this means, of course, an intimate connection between office and works, and a thorough appreciation in the former of the appliances available in the latter. It also means that, in the design of details, much more effective attention must be paid to the adoption of forms which lend themselves to convenient machining than was the case under the older system, and it in every way promotes efficiency and economy.

It is sometimes said that such a system as this, although excellent when certain details have to be turned out in enormous quantities, is not suitable for adoption in works turning out engines or machines in limited numbers and of various sizes. To a certain extent this is quite true ; but only within certain limits. Those who make such a statement fail in most cases to appreciate the extent to which repetition work can be applied to the construction of engines or machines, not only of diverse sizes but of diverse characters. Of course in such engines or machines there are certain special parts, such as frames, bed-plates, &c., which are special to the individual machines ; but, on the other hand, there are an immense number of other details, such as bolts, studs, pins, collars, bearings, lubricating devices and the like, which, with a little careful scheming, can be reduced to a very moderate number of standard patterns and sizes.

It is a common fault in drawing-office practice, when designing a particular machine, to ignore largely the desirability of making minor details agree with details of other machines of a different character produced at the same works. If the part is a casting, there is more chance of an attempt being made to utilise an existing pattern ; but in the case of small forgings, or parts machined out of the solid, it is the exception rather than the rule to find any great care being exercised to secure uniformity. Thus for instance, if a bracket has to be bolted to a frame, it is a common thing to find used for the purpose studs or bolts differing in length by some small dimension from any others used about the machine, when a small difference in the thickness of the bracket flange would enable a standard size to be utilised. To take another instance : the design of glands and stuffing-boxes is a matter which often affords much food for reflection. It is no uncommon

thing, in going through a large works, to find quite half-a-dozen different designs of glands in use on spindles or rods of the same size. There will be differences in the diameter and length of gland, in the size and form of the flange, and in the number and position of the studs ; and for these differences there are, as a rule, no sufficient reasons.   Brass fittings again are too often responsible for an unnecessary multiplication of units.   Thus for instance, the plug of a cock in a set of gauge-glass fittings will be found differing in length, or in some other dimensions, from the plug of another cock of the same bore used for another purpose ; details of unions, or of nuts or washers, will vary unnecessarily on different fittings, and so on. It is however unnecessary to multiply instances.   The point I wish to emphasize is, that in works turning out a variety of machines or engines, if care be taken to resolve these products into their component units, and to classify these units, it will be found that opportunities exist for the introduction of standard parts and repetition work which are frequently entirely unsuspected.

In connection with the subject of standard parts, I may refer to the want which is so strongly felt at the present time, of some really standard series of sizes for pipe flanges, bends, tee-pieces, and connections generally.   Many lists of so-called standard sizes are in existence ; but not only do these differ among themselves, but many of them are quite unfitted for the requirements of modern steam engineering.   What is required is a series of designs and standard dimensions suitable for use in such cases as, say, the equipment of an electric lighting or power station.   Everyone who has had experience in such pipe work, and especially those who have had to extend or couple up with lines of pipes already in existence, knows too well the expense and loss of time which the present want of system engenders.   I am glad to say that this subject is one which it is hoped will be brought prominently before this Institution in the course of the coming session.

While speaking of standard designs and repetition work, I should like to express dissent from the view sometimes put forward : that the execution of work of this kind involves a lower class of engineering practice than the carrying out of a great variety of work.

Those who hold this view have, I think, had little experience of what high-class repetition work really means. In the first place the maker of a machine or engine which he turns out in large numbers must, to be successful, be quite free from anxiety as to the quality of any such machine when it leaves his factory. There must in such a case be no question of improvements or adjustments being effected after the article sold reaches the hands of the purchaser. One cannot conceive the makers of a sewing machine, or of a typewriter, having any anxiety as to the performance of any individual machine they may turn out; and the same should be the case with any machine tool or engine of standard type. This means of course a system of examination and testing of a vastly higher degree of efficiency and exactitude than was deemed necessary under the older methods of manufacture; and as result the purchaser, as well as the manufacturer, gains greatly. Moreover the inspection during manufacture must not be confined to the gauging of dimensions or accuracy of erection, but must extend to the quality of materials used. Where automatic machinery is employed, and every endeavour is made to get all the work possible out of a machine, irregularities in the character of the material operated upon, or in the quality of the tools used, are often disastrous; and thus a careful watch must be kept to avoid such variations.

It must further be remembered that no standard type of machine or engine, however carefully it may be designed and made, will remain a standard for an unlimited period. New requirements continually arise, competition has to be met, and the maker of a standard article of a high class must be ever on the alert if he desires to maintain a leading position. In particular he should, as it were, follow his productions into the hands of his customers, and obtain the fullest information possible of any defects or inconveniences which may show themselves in actual use. No such defect, either in design or in the constructive materials employed, should be regarded as too trivial for attention, but all hints thus gained should be recorded for future careful consideration. The maker must of course avoid too frequent changes in design; but such changes when made must be thoroughly well thought out, both

as regards their adaptability to the machine to be improved and
their mode of manufacture. All these things demand from the
manufacturer of standard types of engines and machines not only
high mechanical skill, but great powers of concentration and attention
to points of detail ; and without these qualifications he can have little
chance of ultimate or continuous success.

It is, I think, evident that the successful mechanical engineer
must nowadays have accurate and definite knowledge respecting
many matters concerning which his predecessors were content to
possess general ideas. We are gathering such knowledge day by
day ; and if the total so far accumulated is but small compared
with that still to be acquired, it is yet sufficient to give us a fair idea
of our ignorance—and this in itself is a great thing gained.

Looking back on the work done by the older mechanical
engineers, before the days of testing machines and chemical and
microscopic analysis, we are apt, I fear, to get a very false
impression of the successes attained. These successes appeal to
our admiration, particularly when we remember the means by which
they were achieved ; but of the failures we have few or no records.
Yet we cannot doubt that these failures were many, and that success
was in a large number of instances only the outcome of experience
gained by long-continued trial and error. Experience of this kind
is most valuable—particularly if its results are faithfully recorded—
but it is also costly, and the modern engineer endeavours to replace
it by the careful use of trustworthy data. It is only during the past
comparatively few years that our knowledge of the strength of
materials has taken anything like a definite form, and there is still
ample scope for the enlargement of that knowledge. It is gratifying
to know that, as regards one class of materials, namely metallic
alloys, this Institution has taken a most leading position in the
matter of research. In fact it is not too much to say that the
experimental work of our Alloys Research Committee, carried out
under the able direction of Sir William Roberts-Austen, has added
more to our exact knowledge of the behaviour of the components
of alloys than any other similar work conducted during the last
decade, either in this country or abroad. We hope soon to receive

from this Committee a further report, which promises to be of great value.

The study of the precise qualities of various constructive materials is certainly one of ever-increasing importance to the mechanical engineer. Called upon as he now is to design machinery for an endless variety of work, and to devise modes of making that machinery, he naturally feels more and more the want of a large choice of constructive materials suitable for certain special requirements. If we compare the works of Nature with the works of man, we cannot fail to be struck by the almost lavish variety of materials to be found in the former. We cannot of course command such variety, nor can we blend materials of widely divergent character in the way which Nature does; but we can by careful research not only vastly enlarge our range of available materials, but can—which is quite as important—ensure regularity in the quality of the materials we select.

If there be one lesson more than another which has been taught by the researches of the past few years, it is the importance of the almost infinitely little. The days when we could be satisfied with a crude approximate analysis of a metal or alloy are gone by; and we are learning that in this, as in all other departments of inquiry, thoroughness can alone give results of real value. We have, I am sorry to say, been slow in this country to appreciate as it deserves the work of the analytical chemist; and our tardiness has cost us much, particularly in certain branches of industry such as the manufacture of dye-stuffs, explosives, &c., but matters are now improving, although engineers, except in a comparatively few cases, are far from availing themselves so freely as they should of the material aid which chemists can frequently afford.

Our knowledge of the effect of small differences in the composition of metals and alloys, and of variations in modes of manufacture or of treatment, has also been materially increased of late years by the employment of microscopic research. To those who inaugurated and to those who developed—and are still developing—this line of inquiry, mechanical engineers owe much. The results, which have been obtained, have only been secured by an immense amount of

concentrated effort. The whole inquiry is one beset with difficulties. The preparation of the specimens, the mode of illumination of the surfaces for examination under high powers, the special treatment of the specimens to emphasize, as it were, the differences of structure, the study and comparison of these differences, and the determination of the lessons to be drawn from them, have each and all demanded not only high skill and perseverance, but an enthusiastic love of the work which deserves our warmest appreciation.

I have said that these microscopical researches have already added much to our knowledge of the structure of metals and alloys, and there is every prospect that in the future results of even greater value may be obtained by their aid. Such researches most admirably supplement chemical analysis. The latter can give us the components of an alloy, or the percentages of carbon or other materials in a sample of steel, with all desirable accuracy. But experience has taught us that, without changing the chemical composition of a metal, its behaviour under mechanical tests may be very materially altered by treatment in various ways; and as to what happens under such treatment, chemical analysis alone gives us little or no trustworthy information. It is here that microscopical research comes to our aid, and gives us facts in place of theories which were more or less guesswork. It is to the microscope that we must look largely for the solution of many questions connected with annealing and tempering, for instance, about which our knowledge is at present of a very unsatisfactory kind.

And here I may say a few words on a point of some interest, respecting which I have frequently found that a misunderstanding exists: and that is as to the size of the details of structure revealed by the microscope. Many of these details so much resemble in general appearance the comparatively coarse crystalline structure that can be seen by the aid of a very moderate magnifying power, that it is by no means uncommon to find a totally false impression existing as to the order of magnitude of the features revealed by microscopic analysis. To those who have not given special attention to such matters, the statement that a certain photograph shows details magnified 200, or 500, or 1,000 times really conveys very

little real meaning.   For instance we have on several occasions had exhibited in this hall lantern slides showing the micro-structure of metals, the image on the screen covering a disc of about 10 feet in diameter.   Now a by no means uncommon magnification in making such slides is one of 200 diameters, and as the slide is in our case magnified about forty times by the projecting lantern, the total magnification of the image, as seen on the screen, amounts to $200 \times 40 = 8,000$ diameters.   But this means that the diameter of the actual surface which we see covering the 10-foot disc is but $\frac{1}{66}$ inch, or about three-fourths of the diameter of one of the very small fine pins which are frequently used for attaching cheques or other enclosures to letters.   Such a result as this however is frequently exceeded; and one very remarkable slide, shown by Professor Ewing on the occasion of his lecture on the "Structure of Metals," delivered at one of our Graduates' meetings in January last,[*] had been prepared with a magnification of 4,200 diameters, enlarged on the screen to over 160,000 diameters.   In this case therefore the image covering the 10-foot disc on the screen represented an actual surface of which the diameter would be less than $\frac{1}{1300}$ inch, or about $\frac{1}{26}$th of the diameter of one of the small pins to which I have just referred.   Bearing this fact in mind, a better idea can be obtained of the dimensions of the details of structure shown by the image exhibited.   It may further bring home the meaning of such a magnification as this if I mention that if magnified 160,000 times a "wave" of yellow light would have a length of about $3\frac{5}{8}$ inches.

The aid afforded to engineers by the microscope, moreover, is not confined to the examination of materials of construction.   It helps us also to a knowledge of the special peculiarities of materials on which mechanical appliances have to operate, as for instance in paper-making, and in the textile industries; and it may also be advantageously used, far more frequently than it is, in studying the effects of wear caused by the friction of rubbing surfaces.

But microscopy is only one of the many branches of physical research which lends aid to the mechanical engineer.   To the various branches of the science of optics, to spectroscopy, to electricity, to

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chemistry, to geology, and to mineralogy, he is indebted in various ways too numerous to consider; while even astronomy has helped him indirectly by putting before him problems of construction only capable of being solved by an accuracy of workmanship which would possibly be otherwise uncalled for. Thus the dividing machines constructed for the graduation of certain astronomical instruments, constitute probably the nearest approach to absolute perfection in machine work which has yet been attained. For instance, the most recently constructed machine of the kind of which I am aware—namely one made by Messrs. Warner and Swasey, of Cleveland, U.S.A.—is capable of automatically cutting the graduations of a circle with an error in position not exceeding one second of arc.* This means that on a 20-inch circle the error in position of any one graduation shall not exceed $\frac{1}{20000}$ inch. Now the finest line which would be of any service for reading purposes on such a circle would probably have a width equal to quite 10 seconds of arc; and it follows that the minute V-shaped cut forming this line must be so absolutely symmetrical with its centre line throughout its length, that the position of this centre may be determined within the limit of error just stated by observations of its edges, made by aid of the reading micrometer and microscope. I may say that after the machine just mentioned had been made, it took over a year's hard work to reduce the maximum error in its graduations from $1\frac{1}{2}$ to 1 second of arc.

But astronomers also call upon mechanical engineers for work of a much heavier class, and work which involves the surmounting of quite special difficulties. For instance, the mounting of such a giant telescope as that at the Lick Observatory at Mount Hamilton, or that at the Yerkes Observatory at Williams' Bay, Wisconsin, is a task far beyond the powers of any ordinary instrument maker, and is really a piece of engineering work requiring not only the highest mechanical skill in its design, but the command of exceptional workshop appliances for its execution. Thus in the case of the

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* A second of arc is approximately the angle subtended by a half-penny at a distance of three miles.

Yerkes telescope, which has an aperture of 40 inches, the weight of
the whole instrument is no less than 70 tons, while the parts which
have to be put in motion to set the telescope on a star weigh 22 tons;
and this weight must be capable not only of being readily moved by
the observer, but of being kept moving steadily at the rate necessary
to counteract the rotation of the earth, and thus maintain the object
under observation in a constant position in the field of view. As
the conditions to be satisfied in this case constitute a problem which
does not often come before mechanical engineers, I may perhaps be
allowed to give a few facts which will serve to indicate the difficulties
to be overcome. The popular idea of these large telescopes is that
they afford enormously magnified images of celestial objects; and
there is, so far, a foundation for this belief in the fact that, with a
large telescope, a greater magnifying power can be employed than
on a small one; and so in the case of such objects as the moon,
planets, nebulæ, or comets, exhibiting definite areas, the images may
be larger than they could be in smaller instruments. But one of the
chief advantages of these large telescopes is not the greater size of
images which they are able to give, but their greater resolving
power, or their power of showing details which in a small telescope
would be entirely lost. This power is illustrated, for instance, by
the effect when observing the fixed stars. These bodies are at such
enormous distances from us, that even in the most powerful
telescopes they behave as simple points of light, and present no area
which can be increased by magnification. It is quite true that when
a star is observed in a good telescope a defined disc is seen; but this
—the spurious disc, as it is called by astronomers—is a diffraction
effect; and it follows from the wave theory of light that the
dimensions of this disc, expressed in angular measures, will decrease
in direct proportion to the increase in the diameter of the object-glass
of the telescope used. In a good 5-inch telescope the spurious disc
shown by a star of about the seventh magnitude—or a star having
a brightness a little less than half that of the faintest star which
can be seen with the naked eye—will have a diameter of rather less
than 1 second of arc; and it thus follows that to be seen as
independent objects in such a telescope, two stars must be not less

than about 1 second of arc apart from centre to centre. But in the Yerkes telescope of 40-inch diameter, the diameter of such star discs would be under $\frac{1}{8}$th of a second of arc; and thus two such stars, which are but $\frac{1}{8}$th of a second of arc apart from centre to centre, can be seen as clearly separate objects, and their relative positions measured.

It has been necessary to mention these facts to explain the problem to be satisfied in the case of the mounting of the Yerkes telescope. In that telescope the star images, of which I have just spoken as having an angular measure of rather less than $\frac{1}{8}$th of a second of arc, will have a linear measure at the focal plane of about $\frac{1}{2500}$ inch in diameter. Now this focal plane is situated at a distance of about 32 feet from the polar axis on which the telescope rotates; while the spider webs—or so-called " wires "—of the micrometer used for star measurements will have a diameter of from about $\frac{1}{5000}$ inch to $\frac{1}{7000}$ inch, or, say, a mean of about $\frac{1}{6000}$ inch. The problem thus is to move this 22-ton mass with such steadiness in opposition to the motion of the earth, that a star disc $\frac{1}{2500}$ inch in diameter can be kept threaded, as it were, upon a spider web $\frac{1}{6000}$ inch in diameter, carried at a radius of 32 feet from the centre of motion. I think that you will agree that this is a problem in mechanical engineering demanding no slight skill to solve; but it has been solved, and with the most satisfactory results. The motions are controlled electrically; and respecting them, Professor Barnard, one of the chief observers with this telescope, some time ago wrote as follows: " It is astonishing to see with what perfect instantaneousness the clock takes up the tube upon the application of the electric clamp in right ascension. The electric slow motions are controlled from the eye-end. They move the telescope slowly in right ascension and declination. Their motion is beautifully steady. So exact are they, that a star can be brought from the edge of a field and stopped instantaneously behind the micrometer wire." It is satisfactory to know that the engineer chiefly responsible for the design and construction of this mounting is one of our own members, Mr. Ambrose Swasey.

I have dwelt at some little length on this question of big telescope mounting, because it forms a good instance of the way in

which mechanical engineers are being constantly called upon to satisfy certain special requirements outside the ordinary course of practice. In some instances these requirements only apply to a certain special case ; in others they may represent the commencement of a new industry. An instance of the latter kind was the demand for novel forms of machine tools for cycle making—an industry which has grown to enormous proportions, and which has, in turn, exercised a most important influence on the development of our workshop practice generally.

Altogether the mechanical engineer of the present day has open before him a vast and ever-widening field of usefulness, which will make the utmost demands upon his resourcefulness and skill, and afford unlimited scope for originality. Thus in the first place the mechanical engineer may be regarded as the chief custodian of that most important component of our national wealth represented by our coal supply. It is not possible to obtain accurate statistics showing what proportion of the 220,000,000 tons or so of coal which we raised last year was used in the generation of power ; but there can be no doubt that the percentage was an exceedingly large one ; and it is to the last degree important that the drain upon our national capital, represented by the fuel so consumed, should not go on without our obtaining the best possible return for such an expenditure.

It has to be borne in mind that, apart from the economy which may be effected by improving the thermal efficiency of the motors employed, there are other ways in which a more or less important saving in the national cost of power may be secured. A mill-owner does not purchase coal because he wants that mineral as a mineral, but because each ton so purchased represents so many thousand units of heat, which can be transformed into the power required to drive his mill. In other words, he purchases power in the condensed form of coal ; and if he could get his power at a cheaper rate, he would be quite content to allow the coal to be utilised elsewhere. Now the cost of the coal to the mill-owner is made up chiefly of two items, namely, the price of the coal itself at the pit and the cost of its carriage to the place where it is utilised ; and if the power, which the coal will develop and which is what the mill-owner requires, can

be transmitted at a less cost than the coal itself, it is evident that the mill-owner will be a gainer. In former days there was no way in which power could be economically transmitted over long distances; but now all this is changed, and the development of electric transmission on an enormous scale appears likely to be one of the chief problems with which our mechanical engineers will have to deal in the next decade. The problem is one having many features, both electrical and mechanical, which are yet very far from being definitely settled, and into the details of which it is impossible to enter on an occasion like the present. One of the most important possibly is the question of steam *versus* gas-driven or internal combustion motors, which is now exciting such great attention and interest. What the ultimate verdict will be, I will not venture to prophecy; but I think that for some long time to come the question of which motor to adopt will be chiefly determined by two factors: namely the class of fuel obtainable, and the market which can be secured for the by-products which form so important an item in the economy of a large gas-driven plant. There is also another feature connected with the working of gas-motors, which appears likely to have an important bearing on their use on a large scale, apart from any question of electrical transmission, and that is the opportunity they afford for economically utilising the heating power of a low-class fuel at a distance from its source of supply. Thus it appears probable that gas made from such fuel, and suitable for use in internal combustion motors, may be distributed over wide areas at a cost which will render it a decidedly economical source of power.

As regards the use of low-class fuels in large power-stations established in the immediate neighbourhood of collieries, or for the manufacture of power-gas for distribution from such centres, there is one important point which must be borne in mind, and that is, that the relative money-values of high- and low-class fuels, if used at their place of origin, are quite different from those which exist if the fuels are used at a distance from such origin. If used in the immediate neighbourhood of the mine, the relative money-values of different fuels will approximate to their relative heating-values; but if used under circumstances involving substantial charges for

transport, the money value of an inferior fuel diminishes in a much more rapid ratio than the diminution of its heating power, owing to transport charges having to be paid on the percentage of inert material.

We thus see that one of the effects of establishing electric-power plants, or power-gas distributing plants, at collieries would very probably be to enable colliery proprietors to obtain remunerative prices for low-class fuels, which are at present not worth extracting ; and in this way there may be effected a material extension of our national fuel supply. This is a result which, on the one hand, would render it unsafe to base the cost of working power-plants at collieries on the present costs of low-class fuel : and, on the other hand, would probably tend to reduce the price of the higher classes of fuel, the demand for which would be lessened.

And here, while speaking of the cost of power, I may remark that the engine builders of this and other countries are, I consider, under a deep debt of gratitude to electrical engineers for the improvements in steam-engine construction which have taken place during the last few years. This is but another instance of the benefit to be derived from exact knowledge. Prior to the introduction of electric lighting on a large commercial scale, improvements in the economy of our steam-engines went on but slowly. Really satisfactory engine-tests were comparatively rare, and it was but seldom, except in the case of large pumping-engines, that strict guarantees of performance were demanded and enforced. The extended use of electric-lighting plant has changed all this, partly owing to the importance of economical motors in such cases, and partly owing to the facilities which the driving of dynamos afford for determining accurately the power developed by engines of large size. The result has been a marvellous reduction in the steam consumption per horse-power ; and it is remarkable that this has for the most part been effected, not by any radical change in engine design, but by careful attention to the points of detail, and by securing a number of small economies.

Another class of problems which have afforded much work for mechanical engineers in the recent past, and which promise to afford

still more in the future, are those connected with transportation. I here use the word " transportation " in its widest sense, embracing not merely the work of carrying passengers or materials from one country or one district to another, such as is effected by our steamships, our railways, and our tramways, but also the transference of materials and products in warehouses or factories. In this world very few natural products are to be found in the places where they are used, and the cost of every manufactured article is largely made up of the cost of transporting from their place of origin, and subsequent handling in the course of manufacture, the component parts of which such an article consists. It has often been said that the existence or non-existence in an engineer's shop of really efficient lifting appliances will alone suffice to make all the difference between profit and loss ; and the same is undoubtedly true of many other establishments.

At our chief shipping ports, on many of our railways, at gas-works, collieries and iron-works, a vast amount has been done to lessen the cost of handling materials, by the adoption of mechanical devices for lifting and effecting internal transport ; but there is still an enormous quantity of such work performed by manual labour, and an engineer who will give proper attention to such matters will find endless scope for his ingenuity in devising appliances to suit special requirements. Under the head of " transportation appliances," moreover, must be included motor cars for passengers and freight, the construction of which is an industry as yet in its infancy and presenting a vast array of unsolved problems, but destined, I believe, in the future to attain most important proportions.

A third class of problems demanding special attention is that connected with workshop practice as affected by machine-tool construction. This is a matter about which I have already had something to say, and I only refer to it again now to emphasize its importance, and to point out the openings it affords for development. Engineers have for a long period been in the habit of devising and constructing machinery for the manufacture in large quantities of articles and products of most varied kinds, such manufactures involving the sequence of a carefully-considered series of more or

less automatic operations. The application of a similar system of manufacture to their own outputs is, however, a matter of comparatively recent growth, and in the bulk of our engineering works its adoption is still in a more or less elementary condition.

It has been of late frequently stated—and with much truth—that, as regards certain points of workshop practice, our friends in the United States are in advance of the mechanical engineers of this country; and it has been strongly urged that we should adopt American methods here. Such advice is very well in its way; but those who offer it fail, perhaps, to realise that its acceptance in a literal sense would, at best, but place us on the level of those imitated. What is really wanted, if we are to maintain our national supremacy as mechanical engineers, is something more than this. Let us by all means study most carefully, not only American methods, but those of Germany, Switzerland, or any other country which is advancing in mechanical engineering work; and then, aided by such acquired knowledge combined with our own long and varied experience, let us do our best to evolve still more improved methods of working, and—what is equally important—let us not hesitate to abandon methods which, however well they may have answered in their time, are now out of date. It cannot be too often repeated that he who copies is always behind him who originates, and it is the first in the race who wins.

The time has long passed when the manufacturers of any one nationality could afford to rest on their laurels won in commercial competition. Nowadays there is no standing still, and a nation must progress or fall back. If it desires to progress, it must work at least as hard as those who are opposed to it, and above all it must keep itself fully informed of all its contemporaries are doing. No policy is so fatal as that which leads a competitor to underrate or ignore the good points in the practice of those with whom he has to compete.

Beyond the three groups of problems to which I have directed special attention, there are many others of almost equal importance. Success in war nowadays is largely a question of mechanical engineering; and improvements in our armaments, in our modes of transport in the field, in our methods of rapidly constructing and

equipping military railways or repairing lines damaged by the enemy, present an almost endless variety of problems. Moreover in the arts of peace generally, as I pointed out in the early part of this Address, the mechanical engineer is taking a position of ever-increasing importance, and without his aid our commerce and our manufactures would practically cease to exist. But while this is so, and while the openings for work are so numerous, it must be borne in mind that, under existing conditions, the mechanical engineer can only hope to obtain prominent success by devoting himself to some particular branch of his profession, and bringing to bear upon that branch not only all his energies, but all the knowledge which he can command.

Let us now, in conclusion, consider briefly how these facts bear upon the future of this Institution—an Institution whose prosperity we all have at heart. The first deduction to be drawn is, it appears to me, this : That great as has been the progress which our Institution has made, and valuable as has been the work which it has done in the past, yet that this progress and this work are as nothing compared to the results which we should attain in the future. The number of our members has grown most substantially during the past few years, and there is every sign of additions going on at an increasing rate ; but the number as yet on our roll represents but a tithe of those eligible for our various classes in this country alone—and we have no desire to limit our membership to this country. With increased membership will come not only a greater diversity of interests, but a more thorough representation of the numerous branches of mechanical engineering ; and to satisfy fully the requirements of these various branches, there will be necessitated not only more frequent meetings and more numerous papers, but also, most probably, an increased amount of specialisation, or organisation of sectional work. Work of this kind has already been carried out to a considerable extent by our various Research Committees, and most important results have accrued ; but the system is capable of very great extension in many ways, and it appears to me to afford valuable facilities for securing the co-operation of a large number of our members in the work of our Institution.

The co-operation, to which I have just alluded, I regard as a matter of the utmost importance. In order that an Institution such as ours may attain its full measure of influence, it must not only command the respect but must excite the interest of everyone connected with it. The Council and the staff of such an Institution may work their hardest; but unless they gain the full confidence and hearty assistance of those they represent, their success will be of a very minor kind. What is required is that everyone on our roll, be he member, associate member, associate or graduate, should feel that our Institution is one to which he is proud to belong, and which deserves his best efforts to promote its growth and prosperity. Such a feeling can only be secured by the governing body being in perfect touch with those they represent; and it is to the cordial relations between our Council and the members which have existed in the past that we must primarily attribute the progress we have made. Let us hope that in the future these relations may be even more cordial and intimate, and our progress greater still.

Sir WILLIAM H. WHITE, K.C.B., Past-President, said that, as the only Past-President at the Meeting, it was his duty and his very great pleasure to propose a vote of thanks to the President for the Address he had delivered. It would be almost impertinent for him, in the presence of the President, to say much in regard to the quality of the Address; but he was sure he was expressing the feeling which the Members all shared, when he said that it had been a privilege to listen to such a eulogy of Mechanical Engineering and to such wise advice as to the future of the profession. The President was eminently qualified to deal with such a subject as he had taken. His life had been spent in reviewing, as well as working in, the various fields of Mechanical Engineering. When

he came forward and gave the result of his ripe experience and careful observation, all who had the welfare of the profession and of the Institution at heart would feel there was much in the Address to treasure and benefit by. There was much food for thought in all that the President had said with regard to the training of Mechanical Engineers, workshop practice, the means of meeting competition, and the bearings which scientific investigation must have on the work of the Mechanical Engineer. He had given to those who were actively engaged in engineering work many most useful hints; and the Address was one which, when published in the Proceedings, would command the deep and careful study not merely of the Members but of all engineers.

Mr. JOHN A. F. ASPINALL, Vice-President, said he had much pleasure in seconding the vote of thanks which Sir William White had so ably proposed. Those who had had the pleasure of knowing the President for many years were well acquainted with his worth, and he was certain that the Members would agree with him that, in the practical and admirable Address he had given, he had added but another laurel to the many which he had already won.

The vote of thanks was carried with applause.

The PRESIDENT, in reply, assured Sir William White and Mr. Aspinall that he appreciated most fully their kind words in proposing and seconding the vote of thanks, and expressed to the Members his appreciation of the very cordial way in which they had received it.

CONVERSAZIONE.

A CONVERSAZIONE was held at the Institution on Friday, 17th May 1901, when the Members and their friends were received by the PRESIDENT and Mrs. MAW. During the evening the Band of His Majesty's Coldstream Guards performed a selection of music, and vocal music was rendered in the Library. Sir Benjamin Baker, K.C.M.G., Member of Council, kindly gave in the large Hall a brief description of the Great Nile Dam, which was illustrated by lantern slides; and a room was set apart for Electrophones. The number of Guests was about 700.

MEMOIRS.

JAMES CHAPMAN AMOS was born at Wandsworth, London, on 19th November 1836. He was educated privately at Ramsgate, and afterwards at King's College School, London. He studied engineering with the firm of his father, Mr. Charles E. Amos, who with Mr. James Easton founded the firm of Easton and Amos, of Southwark, of which he became a partner. He gave considerable attention to improvements in the laying of the earlier submarine telegraph cables, notably the China and Japan extension and the Panama cable for the Dutch Government. His experiments with Mr. Appold on the centrifugal pump resulted in the adoption of their system by the Government in the extension works for the steam basin of the Portsmouth Dockyard. He also directed his attention to boiler economy, and in conjunction with the late Sir William Anderson brought out a boiler on the lines of the French " elephant " boiler. Subsequently he practised as consulting waterworks engineer to the time of his sudden illness in May, 1900, and acted in that capacity to the Falmouth, South Hants, and South Essex Water Companies. His death took place at Hastings on 10th November 1900, in his sixty-fourth year. He became a Member of this Institution in 1867.

The Right Hon. Lord ARMSTRONG, C.B., was born in Newcastle-on-Tyne on 26th November 1810, and was the son of Mr. W. Armstrong, a corn merchant and alderman of that city. He was educated at Bishop Auckland Grammar School, and on leaving it was articled to a well-known north country firm of solicitors, Messrs. Donkin and Stable, later studying in the office of his brother-in-law, Mr. W. H. Watson, afterwards Baron Watson, whose grandson Mr. Watson Armstrong has now succeeded to his estates. In 1834 his legal training being completed he became junior partner in the firm which was afterwards known as Messrs. Donkin, Stable, and Armstrong. He commenced his engineering career as an amateur, making experiments in his leisure time. These distractions became

so engrossing that the practice of the law grew distasteful, and in
1846 he determined to abandon it as a profession, and to cast in his
lot with the mechanical pursuits which had for him so great an
interest. Mainly through the efforts of his friend, Mr. Donkin, a
partnership was formed to set up an engineering business to be
worked by him, consisting of Mr. Donkin, Alderman Armstrong (his
father), and Messrs. Potter, Cruddas, R. Lambert, and himself, the
deed of partnership being signed on 1st January 1847, and a piece
of land was bought at Elswick, on which to erect the works. His
experiments had been largely in the direction of the application of
hydraulic power, and it was to the extension of machinery of this
nature that he devoted his energies. One of the most important of
the early orders obtained by his firm was for the hydraulic
cranes at the Trafalgar goods station at Newcastle.   In 1850
the application of the loaded accumulator gave a great impetus
to the work done by the firm, and the progress made in extending
its field of operations was rapid.   In 1854, when the country
was irritated by the events in the Crimea, he turned his attention
to that branch of engineering construction with which his name
will always be closely identified, namely the problem of the
improvement of ordnance.   At that time all service guns were cast
in iron or bronze, because no means of forging them had been found.
It had been shown by Professor Barlow, that once the pressure
exceeded the resisting power of the material, increase in the thickness
of the gun did not reduce its chances of bursting.   The way in
which Mr. Armstrong (as he then was) overcame the difficulty was
by the plan of shrinking hoops or rings on to an inner barrel.
Another method was to coil a ribbon of wrought-iron into a long
helix, and then to weld it into a solid tube.   This idea had been
suggested by Captain Blakely, Mr. Longridge, and others.   A long
controversy ensued over the claims for priority of invention of this
and the subsequently re-inforced wrought-iron guns designed by him.
He commenced by constructing a small gun—a 3-pounder, which
met with such success that experiments on a larger scale were
recommended.   The gun was consequently bored up to a 5-pounder ;
and as it still gave excellent results an 18-pounder was put in hand,

and then a 32-pounder. In 1859 he made a present of his invention to the nation, and was created Director of Rifled Ordnance, with a salary of £2,000 a year. He also received the honour of a Knighthood, and was created a Companion of the Bath. In 1863 he retired from his official position, and devoted himself to the work of his firm at Elswick.

The advances made in the carriages and mountings of ordnance have been no less remarkable than those appertaining to the gun itself. They were made almost entirely of wood ; sometimes the rear wheels were left out, so that the back part would slide on chocks of wood. In 1864 iron was substituted for wood, and vast improvements were made. From 1860 to 1880 guns had advanced from the 80-pounder of 5 tons up to the 16-inch gun weighing 81 tons—the greatest of the " Woolwich Infants "—but even larger weapons, the four 100-ton guns of nearly $17\frac{3}{4}$ inches bore, were completed in 1878 at the Elswick Works. Such guns demanded an enormous power to command and control them, and here Sir William Armstrong devised hydraulic machinery for the purpose.

In 1858 he joined this Institution, and in the same year read a Paper on Water-Pressure Machinery.* In 1859 he was elected Vice-President, and President in 1861, when he delivered an interesting Address † in which he reviewed engineering developments both in peace and war, and dwelt upon a great engineering want, namely, the ability to produce economically large blocks of homogeneous metal having the quality of wrought-iron. In his Address ‡ on re-election as President in 1862 he contrasted the Great Exhibition of that year with its prototype in 1851, pointing out the great advances shown in the construction of arms and armour. In his third Presidential Address § in 1869, the Centenary of the Steam-Engine of Watt, he reviewed the progress made and dealt with the construction of the Atlantic cable, the Suez Canal, and the first railway across the American Continent. The question of our

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* Proceedings 1858, page 126.

† *Ibid.* 1861, page 110.

‡ *Ibid.* 1862, page 94.

§ *Ibid*, 1869, page 183.

coal supply also received notice, and the influence of Mechanical
Engineering on war *matériel* was discussed at length. His kindly
interest in the work of others, and his own far-seeing views are
patent in every page of these three Addresses, and although the
most recent was delivered thirty-two years ago, they all throw much
light upon modern problems. In 1868 he contributed a Paper on
Hydraulic Machinery, * and in 1869 one on the Hydraulic Swing
Bridge over the River Ouse. † He was an enthusiastic worker in
purely scientific work, particularly in electricity, and in quite recent
years he carried out a number of remarkable and beautiful
experiments on the high-tension discharge. Many of these
experiments are described and illustrated in an elaborate Monograph
which he presented to the Library of the Institution. ‡ His
investigation into the generation of electricity by means of an
escaping jet of steam is well known ; and on this principle he
constructed his hydro-electric machine, which consisted of an
insulated boiler from which steam at high pressure was allowed to
escape through nozzles. This discovery secured his election as a
Fellow of the Royal Society at the early age of thirty-two.

For many years he lived at Jesmond, but in 1863 he purchased a
large tract of rocky and rugged land near Rothbury, Northumberland,
and built for himself on it Cragside, a mansion in the Elizabethan
style ; and in 1894 he purchased the celebrated Castle of Bamburgh
on the Northumberland coast, which he restored on a magnificent
scale. In 1887, on his creation as Baron, he took the title of Lord
Armstrong of Cragside. He was a fellow of the Royal Society,
Honorary LL.D. of Cambridge, Honorary D.C.L. of Oxford, and
Honorary M.E. of Dublin. He received the Albert Medal of the
Society of Arts for his inventions in hydraulic machinery, the
Bessemer gold medal of the Iron and Steel Institute for his services
to the steel industry, and the Telford Medal from the Institution of
Civil Engineers. He was also the recipient of decorations and
Orders of Knighthood from the Sovereigns of Austria, Denmark,

* Proceedings 1868, page 21.

† *Ibid*, 1869, page 121.

‡ "Electric Movement in Air and Water," 1897 ; and Supplement 1899.

Italy, Spain, China, Japan, and Siam. He was President of the British Association at Newcastle-on-Tyne in 1863, when he delivered his celebrated Address on the duration of our coal supply, which led to the appointment of a Royal Commission. He was also President of the Institution of Civil Engineers in 1881. His death took place at his residence, Cragside, on 27th December 1900, at the age of ninety.

RESTEL RATSEY BEVIS was born at West Cowes, Isle of Wight, on 23rd February 1826, and was the second son of the late Captain Bevis, R.N., who for many years represented the Admiralty in Liverpool. In 1840 he commenced a five years' apprenticeship with Messrs. Fawcett, Preston, and Co., of Liverpool. Four years later he was sent to assist in fitting a set of paddle-wheel engines on board the "Barcino" at l'Ormond, near Bordeaux. The next year he was again sent by his employers in charge of a set of paddle-wheel engines to be fitted on board a steamer built in Rio de Janeiro. Having performed this work, he entered the service of the "Compania Braziliera de Paquetes de Vapor" as one of their chief engineers, and in that capacity he made several voyages in their steamers, carrying the mails of the Brazilian Government. In 1847, after having served for a few months as assistant, he was promoted to the position of superintending engineer of the company, which position he maintained until 1853. During that period, owing to the absence of the chief engineer of the arsenal at Rio, he undertook the latter's duties, and was complimented by the late Emperor of Brazil upon the high degree of success attending his supervision of the work. Upon his return to England in 1853, the late Mr. John Laird, M.P., asked him to take charge of the firm's branch shipping yard at the south end of Liverpool. Since then he was closely identified with the work of that firm. In 1868 he invented the now well-known "Bevis" feathering propeller, which was largely employed in the early ships of the Navy in this as well as foreign countries, and which continues in use in sloops and in yachts of all sizes. In 1897 he retired from active participation in the work of the firm, and his eldest son took his place. When the firm was turned into a company,

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his services were retained as a director and consulting engineer, which position he filled until his death. On the death of Mr. William Laird in 1899, he was elected unopposed a Member of the Birkenhead Town Council ; and in November 1900 he was honoured by being offered the Mayoralty, which he had to decline on account of the unsatisfactory state of his health. His death took place at his residence in Birkenhead on 10th February 1901, in his seventy-fifth year. He became a Member of this Institution in 1866.

ROBERT SCOTT BURN was born at Lauder, Scotland, on 14th February 1825. After serving an apprenticeship with Messrs. Watson, Ross and Co., agricultural and brewing engineers, Main Point Foundry, Edinburgh, he went to America for a short time. On his return he resided at Stockport, acting as a consulting agricultural engineer. Subsequently he devoted himself to literary work, and among his earliest productions were "Mechanics and Mechanism," and "The Steam Engine." He also acted for his publishers, Messrs. Ward, Lock and Co., as editor of " The Technical Instructor." For many years he had suffered from bronchitis, from which his death took place at his residence in Edinburgh on 31st January 1901, in his seventy-sixth year. He became a Member of this Institution in 1881.

CHARLES ALEXANDER CROOK was born at Pendleton, near Manchester, on 2nd February 1838. He served five years' apprenticeship in the Britannia Works of Messrs. James Taylor and Co., Birkenhead, a portion of the time being spent in the drawing office. On its completion in 1859, he went to sea as a marine engineer. Subsequently he worked as a fitter in the works of Messrs. Fawcett, Preston and Co. of Liverpool, Messrs. Laird Brothers of Birkenhead, and of Messrs. Blyth and Co. of London. In 1877 he was appointed engineer superintendent to the Telegraph Construction and Maintenance Co., East Greenwich, having charge of the machinery of their submarine telegraph factories, and of the extensive workshops for repairs and manufacture of new machinery, and the engineering superintendence of the fleet of

steamships. He remained in the service of the company to the time of his death, which took place at Bournemouth after a long illness on 7th May 1901, at the age of sixty-three. He became a Member of this Institution in 1884.

Sir ANDREW FAIRBAIRN was born on 5th March 1828 at Anderston, Glasgow, being the only son of Sir Peter Fairbairn. He was named after his grandfather, Andrew Fairbairn, whose two sons William and Peter were successively honoured by royalty. The elder—President of this Institution in 1854–55—received a baronetcy in acknowledgment of his scientific attainments and services, and the younger was knighted when the late Queen visited Leeds to open the Town Hall during his mayoralty in 1858. About five months after his birth his father left Glasgow, and settled in Leeds. With the aid of Mr. John Marshall, he took the vacant Wellington Foundry (which today employs nearly 2,500 workpeople); and here the father started making machines of his own designing, not only for flax and woollen machinery, but subsequently for machine-tools generally.

After attending a school in Leeds, Andrew Fairbairn was placed from 1838 to 1842 under Professor Töpffner in Geneva. He was next sent to the High School, Glasgow, and after attending lectures at Glasgow College, he spent a short time with a tutor at Huntingdon preparing for matriculation at Cambridge University, whither he proceeded in 1847, entering first at Christ's College, and then a few months later at Peterhouse College. After four years' study he graduated in 1850 as thirty-seventh wrangler. In the same year he entered himself as a student of the Inner Temple, being called to the Bar in 1852. After three years spent on the Northern Circuit, he ceased to practise and travelled in the United States. In 1856 he went to Hanover, where he spent the winter studying German, and in the following year returned to Leeds and entered the business of his father. With a view to extending the business of the Wellington Foundry, he went to Germany, Bohemia, Moravia, and Silesia, where he made himself familiar with the practical working of the flax mills. In 1860 he was taken into partnership by his father, on

whose death in the following year he assumed the sole charge of the business until 1863, when he took into partnership his cousin, Mr. T. S. Kennedy, and Mr. J. W. Naylor. In 1882 Mr. Kennedy retired from the firm, which was then converted into a private company, under the style of Fairbairn, Naylor, Macpherson and Co. In 1900 this firm was amalgamated with Messrs. S. Lawson and Sons of Leeds, and Messrs. Combe, Barbour, and Combe, of Belfast, under the title of Fairbairn, Lawson, Combe-Barbour, Sir Andrew being chairman of the joint concern.

In 1866 he was elected Mayor of Leeds, and re-elected in the following year. During the second year of his mayoralty a national exhibition of works of art was opened in Leeds by the Prince of Wales, and the honour of knighthood was then conferred upon him. From 1870 to 1878 he was first chairman of the Leeds School Board; and in conjunction with Lord Frederick Cavendish he took an active part in founding the Yorkshire College, Leeds, in 1874. The success of their efforts is shown by the rapid progress and present prosperity of the College, of which he was for many years treasurer, besides being a life governor, a member of the council, and chairman of the engineering committee. In 1877–8 he was a member of the Royal Commission for the Paris Exhibition in the latter year. In 1878 he was elected a director of the Great Northern Railway, and was also a member of the Great Northern and Great Eastern Railways joint committee. He sat in Parliament for the eastern division of the West Riding from 1880–5, and for the Otley division 1885–6. He presided over the Committee which organised the International Railway Congress, and officiated as the Vice-President when the Conference first was held in Brussels in 1885. For his services in this respect he was created a Knight Commander of the Order of Leopold of Belgium; and when the Congress assembled in Paris in 1889, he acted as President of the first section, and was made a Commander of the Legion of Honour. He was a magistrate for Leeds and for the West Riding, and a deputy-lieutenant for the latter; in 1892–3 he filled the office of High Sheriff of Yorkshire. He had not been in his usual health during the winter of 1900, which he spent

at his house in Biarritz, and was taken ill there with an internal complaint at the end of May. He managed to travel back to his residence in London, where his doctors found it necessary to make an operation. This was performed with success, but the serious effect of his illness became apparent, and his death took place on 31st May 1901, at the age of seventy-three. He became a Member of this Institution in 1868.

GEORGE CHAMBERS FULCHER was born in London on 17th March 1868. He was educated at the Grocers' Company's School, Hackney Downs. From 1884 to 1889 he served his time in the locomotive shops of the Midland Railway, Kentish Town, and attended technical classes during the evenings. In 1889 he was employed as draughtsman at the Nine Elms works of the London and South Western Railway; and in 1891 was engaged by Mr. E. T. Zohrab, late chief engineer of Sykes' Block System, in the design and erection of signalling apparatus. From 1894 to 1898 he was with Messrs. Rosser and Russell, London, designing steam boilers and heating and ventilating apparatus. He then entered the technical department of Messrs. Babcock and Wilcox, London, as draughtsman, and held this position until July 1899, when he entered the Engineer-in-Chief's Department of the General Post Office as draughtsman. This position he retained until his death, which took place at his residence at Stoke Newington, London, on 29th December 1900, in his thirty-third year. He became an Associate Member of this Institution in 1899.

ARTHUR LAING was born in Sunderland on 18th January 1856, and was educated at Wellington College. On leaving school he served an apprenticeship at the North Eastern Engineering Works, Sunderland, and on its termination went to sea for six months in the Inman steamship, "City of New York." He next assisted in the management of the Deptford Shipbuilding Yard, Sunderland, being closely associated with the development of the brass foundry department, which now carries out a large amount of Admiralty and other work. He was interested in a number of shipping and

other companies, and was managing owner of the " Dale " steamers and director of the Neptune Steam Navigation Co. His death took place at Sunderland on 16th March 1901, at the age of forty-five. He became a Member of this Institution in 1881.

JOHN WALKER LOGAN was born at Berwick-on-Tweed on 31st January 1850. He served his time from 1867 to 1872 in the shops and offices of Messrs. J. Jack and Co., of Liverpool, and on its completion started business in partnership with Mr. Elder as agricultural implement makers at the Tweedside Works, Berwick-on-Tweed. When the partnership was dissolved, he carried on the business in his own name, but in 1888 he went to South Africa in the service of Messrs. Mackie, Dunn and Co., and was subsequently engineer to Messrs. Richard Hornsby and Sons at Johannesburg. In 1893 he was appointed sole agent for Messrs. Davey, Paxman and Co., of Colchester. On the outbreak of the war, he removed to Cape Town, where he contracted enteric fever, to which he succumbed on 17th March 1901, at the age of fifty-one. He became a Member of this Institution in 1890.

GEORGE BEST MARTIN was born on 11th December 1847, near Brighton. He received his education at Cliffe House Academy, Lewes, from 1859 to 1863. On leaving school he gained workshop experience in a small repairing shop attached to a steam and water flour-mill belonging to his father at Horsebridge, Sussex. At the age of twenty he determined to adopt engineering as a profession, and was articled in 1869 to Mr. N. P. Burgh, consulting engineer, of London. At the expiration of his time in 1871 he was engaged as draughtsman for about nine months by Mr. Symington, engineer to the A.B.C. Sewage Co. In 1872 he entered the drawing office of Messrs. James Watt and Co., Soho Foundry, Birmingham, where he remained until 1895, when the works were dismantled. During the last sixteen years of that time he was chief draughtsman, and designed a great deal of work, being chiefly responsible for the details of work for the shops. With the late Mr. J. W. Gray he designed the large pumping engines at Whitacre for the Corporation

of Birmingham. He took great interest in tube drawing, especially in solid-drawn steel tubes, and the difficulties of that process were largely surmounted by his and the late Mr. W. C. Stiff's skill and experimental labour. Hence when he left the Soho Foundry, he became works manager to the British Seamless Steel Tube Co., and ultimately general manager. He brought out many processes and inventions for the manufacture of steel tubes, and also aluminium tubes. For annealing the latter he designed a special furnace heated by superheated steam. He resigned his position of general manager in October 1900 through failing health, brought on by influenza, and went to Bournemouth, where his death took place on 15th February 1901, at the age of fifty-three. He became an Associate Member of this Institution in 1896.

HENRY CRIPPS MATHESON was born in Nottingham on 28th October 1857, and was educated at the Grammar School, which afterwards became the Nottingham High School. After training as a mechanical engineer at the works of Messrs. Handyside and Co., Derby, he entered in 1877 the drawing office of Messrs. Manlove, Alliott and Co., Nottingham, and became head draughtsman there in 1879, a post which he held until 1882. In 1883 he went to China as representative of Messrs. Matheson and Grant, engineers, London, and lived for some years in Hong Kong. In 1887 he took up his residence in the island of Formosa, which had then been made a separate province. There he superintended the works in connection with the collieries at Keelung, and in 1889 became consulting engineer for the railway,* which had been sanctioned by the Chinese Government. On his retirement at the end of 1894 he received from the Emperor the Order of the Double Dragon of the second class. He then returned to England, and entered the service of Messrs. John Birch and Co. in February 1895, for whom he went out to Japan; soon after his return he went to Egypt, where he made preliminary plans for light railways in the Delta, now working with

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* *Paper* on "The Formosan Government Railway," by H. C. Matheson—
Proceedings, Institution of Civil Engineers, 1891-2, vol. cix. page 322.

success, and also assisted the late Mr. John Birch in projecting a
" desert " railway.   After several visits to Egypt he became in 1899
a managing director of Messrs. John Birch and Co.   In September of
the same year he went out to China with Mr. J. G. Birch, and
travelled up the Yang-tze Kiang to Chung-King.   There they parted,
Mr. Birch going northwards to the Yellow River, and Mr. Matheson
travelling across country to Canton.   From there he went up to
Shanghai and Tientsin, where he arrived just in time to take part as
a volunteer in the defence of the town.   Returning to Shanghai he
heard the news that Mr. Birch had been drowned by the wreck of a
raft on the Yellow River.*   After some stay in China and a visit to
Formosa, now under the Japanese Government, he was coming home
to England with the hope of soon returning to China, when he was
drowned in the wreck of the s.s. " Rio de Janeiro " off San Francisco,
on 22nd February 1901, at the age of forty-three.   He became a
Member of this Institution in 1882.

ALEXANDER JOHN MURRAY was born in 1852.   He served an
apprenticeship in the upper turnery department of H.M. Dockyard,
Bombay, from 1868 until 1872, and was one year in the Bombay,
Baroda, and Central India Railway Works at Parel.   He was next
engaged as a mechanic at the Small Arms Ammunition Factory at
Kirkee, being promoted to assistant mechanical engineer in 1883,
and since 1890 he was chief mechanical engineer.   His health had
been indifferent for some time prior to his death, which took place
at Kirkee in January 1901, in his forty-ninth year.   He became
a Member of this Institution in 1890.

THOMAS OWEN was born at Llanelly on 11th June 1854.   He was
educated at the High School, Llanelly, and served his time from
1870 to 1874 partly at the Millbrook Foundry, Swansea, and partly
at the Plymouth Iron Works, Merthyr Tydfil, passing through the
fitting shops, drawing office, etc.   He was next appointed in charge
as mechanical engineer for the Felling Coal and Iron Co., Newcastle-

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* Proceedings 1900, page 623.

on-Tyne. In 1875 he gave up his post in order to inspect some bridges for the Norwegian State Railways. In 1876 he joined the staff of the Midland Railway as chief inspecting engineer of permanent-way materials, which position he occupied until his death, after a short but severe illness, on 25th January 1901, in his forty-seventh year. He became a Member of this Institution in 1889.

CHARLES HENRY PUGH was born at Newtown, Montgomeryshire, on 6th June 1840, and was the second son of Richard Pugh of that town. He was educated at Welshpool Grammar School, and in his eighteenth year after a visit to Canada entered his father's ironmongery and general hardware business. In 1860 he became manager to Messrs. Mellard of Uttoxeter, Staffs., ironmongers and implement makers, and while there brought out his first invention—one for improvements in cheese-making machinery—which was successfully worked for many years. In 1867 he bought the ironmongery business of Messrs. Brooks of Rotherham, to which he added a wholesale department. This business he sold in 1872 and removed to Birmingham, where he founded the Screw, Rivet, Bolt and Nut Works at Dean Street and Bishop Street, and subsequently at the Whitworth Works, Rea Street South, of which he remained owner till his death. In 1891 he added to this business a bicycle works in partnership with his eldest son under the style of the Whitworth Cycle Co. Owing to its rapid development this was in 1893 converted into a private company, and in 1894 was amalgamated with the Rudge Cycle Co., of Coventry, under the style of "Rudge-Whitworth Limited," now one of the largest and most successful cycle manufacturing concerns in the United Kingdom. In 1892 he was led by difficulties in building bicycle wheels to investigate the subject of making for them steel rims which should be mathematically true and circular. The result of a long and costly series of experiments was his invention of the jointless rim, to manufacture which he founded in 1894 the Jointless Rim Co. He sold his interest in this business in 1897, and since then had been constantly travelling abroad for health. His death took place at his residence, Hawthornden, Penns, near Birmingham, on 9th

April• 1901, in his sixty-first year. He became a Member of this
Institution in 1890 ; and was also a Member of the Iron and Steel
Institute.

THOMAS SPENCER was born at Newburn, Newcastle-on-Tyne, on
24th December 1825. He was the fourth son of Mr. John Spencer,
founder of the firm of J. Spencer and Sons, Newburn Steel Works.
After receiving his education in private schools, he entered into the
active business of the firm, and in time took up the commercial work,
acting chiefly as travelling representative. As the firm have taken a
prominent part in the development of the railway system from its
earliest times by supplying the various locomotive works and railways
with their requirements of material, there was a large field for his
ability and energy. After an active business career he retired in
1871 owing to ill health, and had since chiefly lived abroad. He was
well known in the north of England for his gifts towards religious
and educational purposes. In July 1900 he had an attack of paralysis,
from which he was slowly recovering when he was seized with
bronchitis, upon which pneumonia supervened, to which he succumbed
on 12th April 1901, at the age of seventy-five. He became a
Member of this Institution in 1854.

THOMAS WATERHOUSE was born in Birmingham on 1st December
1821. After receiving his education in Birmingham and Bristol, he
commenced his business career in the capacity of agent in America
for Messrs. W. and S. Butcher, of Sheffield. Subsequently when Sir
Frederick (then Mr.) Mappin purchased the business of Thomas
Turton and Sons, at Sheaf Works, Sheffield, he went to assist that
firm at Mr. Mappin's request, and remained there during a long
course of years. On the conversion of the business into a private
company, he became a director, though in later years failing health
compelled him to lead a retired life. Among his inventions was a
compressed air forge-hammer and pile driver, which was brought
out in 1855, and made at Gorton Foundry. His death took place at
his residence in Sheffield on 15th December 1900, at the age of
seventy-nine. He became a Member of this Institution in 1858.

JOHN HENRY WIDDOWSON was born in Manchester on 22nd September 1828. After serving an apprenticeship with Mr. W. Bolton, engineer, of Castlefield, Manchester, he went as engineer to Messrs. Booth and Pike, introducing many improvements in the machinery; subsequently he was with Messrs. Muir and Co. In 1851 he was engaged by Messrs. Joseph Whitworth and Co., Manchester, and after passing through the position of foreman and under-manager was appointed manager in 1860, which position he held until 1876. In that year he started business on his own account as a manufacturer of screwing tackle in all its various branches. His death took place at his residence at Moss Side, Manchester, on 12th May 1901, in his seventy-third year. He became a Member of this Institution in 1891.

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Fig. 25.
6-inch Lathe with Special Change-Gear.
(Hendey-Norton, see Plate 27.)

Mechanical Engineers 1901.

Fig. 26.   6¼-inch Lathe (Humpage, Jacques, and Pedersen).
Suitable for brass finishing, and also for heavy work.

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Mechanical Engineers 1901.

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Toggle-Joint A.

Gear 3·96 to 1

38 T · 8 P

104 T · 8 P

84 T · 8 P

96 T · 12 P

58 T · 8 P

48 T · 12 P

A

Inches 12   6   0   1   2 Feet

Fig. 29.

Change-Feed-Motion (Lang).

0   3   6   9   12 Inches

Fig. 30.

Change-Feed-Motion (Archdale).

0   3   6   9   12 Inches

Fig. 31.

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Mechanical Engineers 1901.

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Mechanical Engineers 1901.

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Plan.

Front

0   3   6   9   *12 Inches*

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Mechanical Engineers 1901.

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Mechanical Engineers 1901.

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Mechanical Engineers 1901.

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Inches 12   6   0   1   Feet 2

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Mechanical Engineers 1901.

Flat-Turret Lathe ("Hartness," by Jones and Lamson).

Fig. 59. Headstock.

Inches 12   6   0   1 Foot

Plate 30.   LIGHT LATHES AND SCREW MACHINES.   *Plate 30.*

Flat-Turret Lathe ("Hartness," by Jones and Lamson).

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Fig. 62.   *Turret.*

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Mechanical Engineers 1901.

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Fig. 65. *Swedish Universal Turret-Lathe.*
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Mechanical Engineers 1901.

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(*Photo, see Fig. 64.*)

Details, see Figs. 54 and 57 in letterpress.

6 Step Rods

T Screw T.P

Reversing Lever

Tank

Roller Feed

2½ hole

Ins 12   0   3   6   9 Feet

Fig. 67. *Details of Automatic Trip Gear of above Lathe.*

25 Inches   20   15   10   5   0

Mechanical Engineers 1901.

Fig. 68. *Details of 9-inch Flat Turret (Ward).*

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5-inch Capstan Lathe (Ward).

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0   3   6   9   12 *Inches*

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Mechanical Engineers 1901.

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Mechanical Engineers 1901.

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Mechanical Engineers 1901.

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Fig. 81.

Fig. 82.

D

Chasing Saddle.

9-inch Capstan Lathe.
(Ward.)

Fig. 80.

E A B D

F

1 Foot

0

6

12 Inches

Fig. 83. Chasing Saddle.
Capstan Lathe (Herbert), No. 5.

2 Feet

1

0

6

Inches 12

LIGHT LATHES AND SCREW MACHINES. Plate 41.

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Mechanical Engineers 1901.

Fig. 86.
Headstock.

Stock Tube   *Chuck Tube*

Spindle

100 T - 5 P

Ins. 12   6   0   1 Ft.

25 T - 5 P

Fig. 87.   *Turret.*

Inches 12   6   0   1 Ft.

Mechanical Engineers 1901.

Fig. 88.
Cam-shaft Drive.

Inches
12   6   0   1 Ft

Diagram showing method of setting out Cams.

Fig. 89. *Diagram for obtaining Cam-plate angles.*

Size of Pulleys
Machine 14"
Countershaft
Driving 16"
Feed 8"

Cuts per inch
100
110
120
130   140
150 160
170 180
190 210 200
220 240 230
250 300
350 400
500 600 700
800

Distance measured across the Drum, parallel with the Axis.

Fig. 90. *Arrangement of Cutting-off Cams.*

17¾
7¾
200 Cuts   100 Cuts
12¾
45
16¾

Distance measured round the Periphery of the Drum

Fig. 91. *Developed View of Cam Drums.*
(Plates in position for producing bolts

Fast Feed | Slow Fast Feed | Slow Feed | Fast Feed | Fast Feed | Slow Fast Feed | Slow Fast Feed | Reverse | Fast Feed

Reaching
Unlocking
Turning

150 Cuts   180 Cuts   100 Cuts   Tool Clears   Chuck opens

Fig. 92.

Shank Feed Chuck
Closed
Open

ZERO

Plate 44.

Fig. 93.

Automatic Screw-Machine (Cleveland).

Inches 12   6   0   1   2 Feet

Mechanical Engineers 1901.

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Fig. 100.
Turret.

P

O

M

Fig. 101.
Headstock.

E

E

D

Fig. 99.
Cam-driving Mechanism.

A

B

F

G

L

N

N

E

C

B

A

F

G

L

N

H

J

K

E

F

I

A

B

A

C

E

N

N

*Details of Automatic Screw-Machine (Wolseley).
(Photo. See Fig. 85.)*

Inches 12   6   0   1 Foot

Plate 48.

Fig. 102. Vertical-Turret Automatic Screw-Machine (Brockie).

(Details, see Plate 49.)

Plate 49.

LIGHT LATHES AND SCREW MACHINES.

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Fig. 104.

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12 Inches   6   0   1 Foot

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Mechanical Engineers 1901.

TROLLEY-CONDUIT ELECTRIC TRACTION. *Plate 53.*

Fig. 1. *Side-Slot Switch.*

Section at AB

Beginning of Curve

Fig. 2. *Centre-Slot Switch.*

A

B

Insulators and Suspended Conductor Rails (Central Conduit).

Fig. 3. *In Washington.*

Fig. 4. *In Paris.*

Wheel Rail Level

Centre of Tramway

Centre of Tramway

Fig. 5. *For Conduit where depth is restricted.*

Pont de l'Alma, Paris, etc.

0   5   10   15   20   25   30 Inches

Mechanical Engineers 1901.   *Scale for Figs. 3, 4 and 5.*

Special Shallow Conduit, Pont de l'Alma, Paris.

Fig. 6. Section | at Casting.

(See Fig. 9,
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Fig. 7. Section | of Insulator.

Fig. 8. Plan.

Inches 12   6   0   1   2 Feet

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Fig. 11. *Siding without Conduit, Paris.*

Mechanical Engineers 1901.

Plate 56.

TROLLEY-CONDUIT ELECTRIC TRACTION. Plate 56.

Counter-weight Mechanism
for closing rail-switches automatically, Paris.

Fig. 12.
For Centre-Slot.

Fig. 13.
For Side-Slot.

Inches 12   6   0   1   2   3   4   5 Feet

Plate 57.

TROLLEY-CONDUIT ELECTRIC TRACTION.

Deflection of Side-Slot to Centre-Slot at Switch, Paris. (Locking Mechanism, see Plate 56.)

Fig. 14. General Plan.

Fig. 15. Details of above.

Radius 14ᵐ

200 Inches

Angle 16°

Radius 25ᵐ

Trap Door

Beginning of Curve

Beginning of Curve

Pl. 57.

200 Inches

A = Special Chairs

Trap Door

For extracting 'dead' plough

Mechanical Engineers 1901.

Fig. 16. *Deflection of Side-Slot to Centre-Slot, Paris.* (*See Plate 57.*)

Fig. 17. *Tramway- and Conduit-Switch, Paris.*

TROLLEY-CONDUIT ELECTRIC TRACTION.

Plate 59.

Centre Line of Trap

Inches 12 6 0 1 2 3 4 5 6 Feet

Fig. 18.

Trap-door Mechanism for Plough, operated after Car has reached its position.
Bastille-Charenton Tramway.

Mechanical Engineers 1901.

Plate 60.

TROLLEY-CONDUIT ELECTRIC TRACTION. *Plate 60.*

Fig. 19.

Plough, with raising and lowering device, Paris.

Underside of Car Flooring

Plan.

Inches 12 6 0 1 2 3 1 Feet

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Mechanical Engineers 1901.

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Fig. 23. *The same.*

Fig. 24. *The same.*